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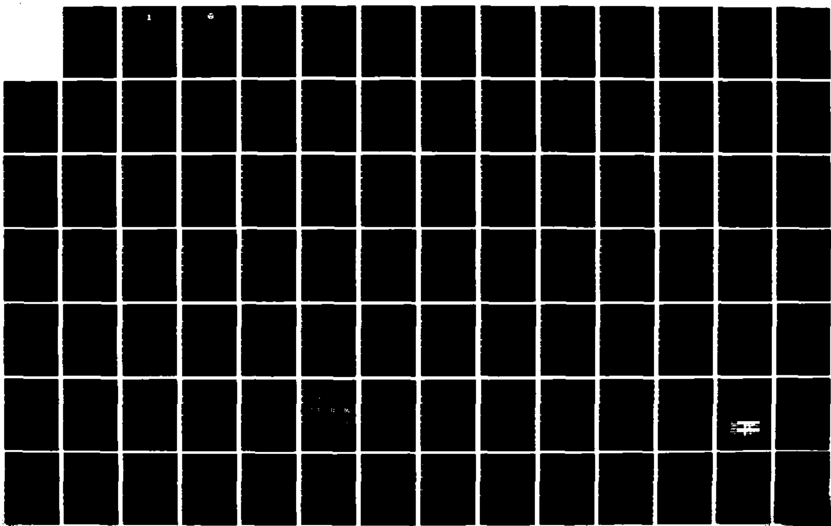

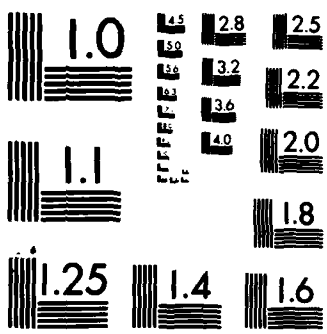

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EIGHTH ANNUAL REPORT
ADVANCED MAIL SYSTEMS TECHNOLOGY

Executive Summary and Appendixes A-C

November 1983

Reporting Period: 1 May 1982—30 August 1983

Prepared by
NOSC Signal Analysis and Image Processing Division
(Code 732)
NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152

Prepared for
US POSTAL SERVICE
OFFICE OF ELECTRONIC MAIL SYSTEMS DEVELOPMENT

NAVAL OCEAN SYSTEMS CENTER SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

J.M. PATTON, CAPT, USN
Commander

R.M. HILLYER
Technical Director

ADMINISTRATIVE INFORMATION

This report contains a summary of work sponsored by the Office of Electronic Mail Systems Development, Research and Development Department of the U.S. Postal Service, Rockville, Maryland 20852, under U.S. Postal Service Agreement 104230-81-T-0847. The authorized USPS Technical Representative is A. I. Tersoff. T. B. Barnum provided most of the detailed NOSC guidance for the USPS. The principal NOSC investigator is L. A. Wise, Image Processing Branch, NOSC Code 7323. Associate investigators are F. C. Martin, R. J. Wagar, R. W. Basinger, C. E. Dempsey, and R. G. Moreland, also in Code 7323. P. C. Grossnickle, now in NOSC Code 7331, participated throughout most of the reporting period. W. R. Robinson, Code 8235, also made major contributions to the project. This report is a compilation of data contributed by all team members and was approved for publication November 1983.

Released by
R. L. Petty, Head
Signal Analysis and
Image Processing Division

Under authority of
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METRIC EQUIVALENTS

To convert from	to	Multiply by
inches	mm	25.4
square inches	m^2	$\sim 6.45 \times 10^{-4}$
feet	m	$\sim 3.05 \times 10^{-1}$
miles	km	~ 1.61
pounds	kg	$\sim 4.54 \times 10^{-1}$

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Data compression	Optical scanning	Solid-state scanners
Image acquisition	Photodiodes	Video processing
Image processing	Run length coding	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of the effort described herein is to provide technical consultation, equipment, and support services to the US Postal Service that will contribute to the development of the system definition of future electronic mail processing systems. Included in the scope of effort are investigations of high-speed image scanning technology, image frame memory storage, and image enhancement as well as fabrication of a scanner/frame-store memory test assembly. The eighth annual report briefly describes the individual efforts of the reporting period in an executive summary and provides in-depth data in three appendixes: Appendix A, Text Character Compression Study; Appendix B, USPS E-COM Logo Study; Appendix C, NOSC Logo Project Plan for Graphics Conversion Subsystem.

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Third Annual Report, Advanced Mail Systems Scanner Technology, NOSC TR 170, October 1977, DTIC AD A051508

Fourth Annual Report, Advanced Mail Systems Scanner Technology, NOSC TR 358, October 1978, DTIC AD A070546

Fifth Annual Report, Advanced Mail Systems Scanner Technology, NOSC TR 520, October 1979, DTIC AD A089436

Sixth Annual Report, Advanced Mail Systems Scanner Technology, NOSC TR 642, October 1980, DTIC AD A097493

Seventh Annual Report, Advanced Mail Systems Scanner Technology, NOSC TR 812, May 1982, DTIC AD A122927

Also see:
CCD Page Reader for Mail-Scanning Applications, Final Report for period 15 March 1976 to 15 May 1977, RCA Princeton Laboratories Report PRRL-77-CR-42, DTIC A062399

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OBJECTIVES

1. Provide for the US Postal Service the consultation, equipment, and support services that will contribute to the generation and improvement of advanced mail transmission systems such as International Electronic Posting (INTELPOST) and Electronic Computer Originated Mail (E-COM). Included in this scope of effort are:

a. The investigation of scanner technology, memory technology for storage, sorting, and retrieval of messages and images, and data compression technology, including error detection and correction (EDAC).

b. The design, fabrication, and operating support of a scanner/frame store memory test assembly.

2. Contribute to the selection of optimal devices, equipments, and techniques for high-speed image acquisition. Provide reliable designs of high-speed image processing logic that will preserve the quality of the image while reducing the image storage and transmission requirements and that will minimize image information vulnerability to noise during processing, transmission, storage, sorting, retrieval, and reproduction.

3. Act as technical consultants to the USPS Office of Electronic Mail Systems Development in preparing technical requirements and statements of work and in evaluating technical proposals and contractor performance. Also, perform technical evaluation of contractor-produced developmental equipment.

RESULTS

1. The Image Capture and Analysis System (ICAS) has gone through evolutionary upgrades over the years and has reached maturity. It offers the ability to rapidly acquire, analyze, store, exploit, display, and print images and their statistics.

2. As a result of increasing USPS priorities for the addition of graphic images such as logos, forms, and perhaps signatures to E-COM messages, much emphasis has been applied to generating near- and long-term methods of acquiring, manipulating, storing, and printing digitized facsimile images at a number of Serving Post Offices (SPOs) in widely separated cities.

3. An analysis of character compression has been performed. The results indicate that text compression can yield a saving of approximately 30% of transmission bandwidth and digital storage requirements, at some increase in system cost and complexity due to the need for companding equipment.

4. An analysis of the impact of adding the use of imagery data to a vast system such as E-COM has been performed. Numerous alternatives for candidate site data handling equipments, intercommunication equipments, image storage and transmission media, and interfaces to the existing operating site subsystems have been considered, and the results of the tradeoffs have been documented.

5. After establishing goals and requirements for the addition of graphics to E-COM, NOSC and the USPS generated a list of applicable equipments that could be used at NOSC in the generation of two prototype subsystems for the E-COM system. One of these is a prototype graphics conversion subsystem. The other is a low-cost prototype printer subsystem offering higher document speed and higher resolution than is now produced by the existing E-COM printers. At the time of publication of this document, most of the components required are in the procurement cycle.

6. Delta Information Systems has completed a contracted study of image compression techniques. Copies of the final report reside at NOSC and the USPS R&D Laboratories.

NOSC PLANS

IMAGE ACQUISITION STUDIES

1. Design and fabricate a prototype graphics conversion subsystem.

2. Develop user-friendly software for the rapid acquisition, framing, and cosmetic restoration of customer images on the graphics conversion subsystem.

3. Evaluate the adequacy of optics, illumination, focus, and spatial resolution aids for acquisition of quality images of proper dimensions.

4. Contribute to the generation of USPS guidelines for customer graphics copy input specifications.

5. Assist in the design and initial operation of a productive graphics conversion subsystem at the USPS R&D Laboratories at Rockville, MD.

6. Complete the evaluation of the RCA TDI imager; document the results.

IMAGERY DIGITIZATION AND MESSAGE DATA COMPRESSION STUDIES

1. Design and fabricate a prototype high-performance printer subsystem.

2. Develop suitable software to provide the interface between existing SPO hardware/software and the new printer subsystem.

3. Evaluate the performance of the printer subsystem with regard to print (image) quality, document throughput, size and placement accommodation of graphic data, and minimum impact on existing SPO hardware/software.

4. Assist in establishing an upgraded model of a printer subsystem at the USPS R&D Laboratories at Rockville, MD.

MASS STORAGE STUDIES

1. Use the output parameters of the graphics conversion subsystem and the graphics and text input requirements for the printer subsystem to define the requirements for image storage media needed to accommodate near- and long-term volumes of graphics imagery at SPO E-COM sites.

2. With sample graphics of various sizes and complexities, compute compressibility ratios by employing several of the most promising image compression algorithms.

3. Determine the practicality of incorporating compression techniques with memory storage and retrieval, to minimize decompression speed and real-time hardware complexity.

4. Review the tradeoffs leading to the tentative decision to use magnetic tape for graphics information dissemination and interchange among SPOs.

IMAGE PRESENTATION STUDIES

1. Evaluate image exploitation algorithms designed to assist in compensating for quality degradation due to differences in the point spread functions of the camera optics, the graphics conversion subsystem displays, and the printer subsystem pel characteristics.

2. Incorporate the most successful of these algorithms into the hardware/software of the work stations.

CONTENTS

EXECUTIVE SUMMARY

PROGRAM GOALS

The major goals of the Advanced Mail System's Technology Program changed from those of previous years during the reporting period. In the past, the goals have been to identify and resolve problems associated with the production and manipulation of digital images from a wide variety of monochrome and color facsimile (bilevel) and continuous tone (grey scale) hardcopy originals. With the exception of some of the compression technique investigations, the generic goals listed below have been achieved.

- High-Quality Image Acquisition
  - Either orientation of 8-1/2- by 11-inch documents
  - Typed, handwritten, or continuous-tone images
  - Monochrome or color images
  - Resolution up to 200 by 200 or 300 by 300 pels per inch
  - Up to 84 megapels (504 megabits) per second
  - Image enhancement
    - Edge enhancement
    - Nonlinear video techniques
    - Thresholding
    - Color filtering
- Image Bandwidth Compression Techniques
  - Run-length encoding
  - Walsh, slant, or Fourier encoding
  - Block void encoding
- Mass Memory Studies
  - Imagery memory technology
  - Memory buffers for imagery applications
  - Image storage, sorting, and retrieval
  - Error detection and correction

1982/1983 TASKS

This report is the eighth in a series of "annual" reports and covers the project activities from 1 May 1982 to 30 August 1983. During this reporting period the focus has centered on a specific USPS near-term need, that of expanding the capability of the Electronic Computer Originated Mail (E-COM) System to allow customers to add graphics information such as logos to their messages.

HARDWARE ACCOMPLISHMENTS

Image Capture and Analysis System

The Image Capture and Analysis System (ICAS) consists of a four-bay suite of special hardware equipments designed to evaluate image acquisition quality with new sensor and optical components. Except for the lack of memory capacity to store full-page continuous tone images at resolutions above 200 by 200 pels per inch, the design accommodates all current USPS image acquisition and processing goals.

The system has produced digital tapes of logo samples for the evaluation of the Delphax printer. It has also calculated the run-length compressibility for these acquired images.

There have been no appreciable revisions to the ICAS hardware during the reporting period. Except for the Comtal Vision One display system, the equipment has been quite reliable. No hardware modifications or upgrades are planned for ICAS. Its resources–such as tape decks, terminals, and frame store memory– are usable as they exist for supporting the introduction of graphics to E-COM.

TDI Imaging

A contract from the USPS to RCA Princeton Laboratories for the development of a time delay and integration (TDI) imaging device for very high speed electronic image acquisition was completed during the previous year's reporting period. Delivery consisted of 17 scanner devices and a display exerciser. The devices had passed probe tests at RCA and represented the best samples from several wafer runs produced in Princeton's integrated circuit laboratories. The exerciser produces the voltages and waveforms required to operate the 64-pin devices at high speed. All hardware from the contract was delivered to NOSC for further evaluation and device characterization.

During this reporting period, several iterations of improvement in the instrumentation were accomplished. Most of these were related to improvements in the control of the phasing and rise-time of the clocking waveforms. Power supplies and an independent interface to a Tektronix 4051 were added so that the TDI tests can be run without the use of the ICAS.

Early in the reporting period we received a lens designed and fabricated by Alpha Optical Corp under contract by George Merkson of the USPS. This 85-mm f/1.4 lens has been fitted to the Scanner III optical bench. The resulting acquired images are much superior to those obtained with the Nikon f/3.5 Auto Micro Nikkor usually used, both in resolution and uniformity of brightness across the field. Although the focal length is longer than optimum for some of the requirements of ICAS, it is used whenever possible.

SOFTWARE ACCOMPLISHMENTS

In contrast to the developments of previous years, relatively little new software has been generated during the reporting period. Some refinements to the six-bit/eight-bit software were made during the reporting period. For almost all applications, the existing ICAS software has been adequate without modification.

Thinning Algorithm

In the preliminary tests of logo acquisition, storage, display, and printing, it was found that logo images acquired and presented at 240 by 240 pels per inch through the use of the Datacopy camera and display are soft images closely matching the appearance of the original. When printed on the Delphax ion deposition printer or the HP laser printer, the black areas of the logos spread and encroach on the white areas because of growth of the spot diameter during printing. A primitive test of a thinning algorithm was written in BASIC on the ICAS 4054 terminal. This program and its sample plots seem to indicate that the thinning process is useful in diminishing the spreading of black areas during the printing process. The thinning algorithm can strip or peel one layer of black pels from all or selected boundaries of the logo image. The algorithm simulated by means of the ICAS Tektronix 4054 terminal was found to be a promising fix for the point spread function growth of the printer. This capability will be incorporated into the graphics conversion subsystem software.

E-COM SUBSYSTEM SUPPORT ACCOMPLISHMENTS

The NOSC investigators have been given an opportunity to study several facets of the E-COM system. Two draft working documents have been generated: a system requirements document and a system alternatives document. Neither is included in this report since neither currently reflects the latest USPS plans for the E-COM system. It is expected that the architecture of E-COM will again stabilize once an adequate graphics capability has been incorporated. At that time these documents will be updated and submitted. A separate description of text character compression is included as appendix A.

E-COM Logo Study

One of the most interesting tasks of the reporting period was a study of some of the major impacts related to the addition of graphics such as logos and/or signatures to E-COM messages. The results of this study are included in this report as appendix B. This summary provides an overview of the results of the study at NOSC to analyze specific areas of the acquisition, transmission, compression, storage, and printing of logo and signature images.

We have reviewed the storage capacity and communications channel requirements to add the capability of accommodating three sizes of high-resolution graphics areas to the existing E-COM system. The resolution chosen was 240 by 240 pels/inch as a maximum worst-case requirement. The three sizes of graphics chosen were 1 inch square, page width by 1 inch high, and full page area. The use of lower resolution logos is discussed. We understand that the principal USPS interest is in logos. We feel that it may be of future value to allow USPS customers the latitude to utilize the bilevel (black/white) image areas for an unlimited number of images, including signatures.

We have discussed three types of landline/microwave networks and a satellite network. Our preliminary conclusions indicate that a broad-band satellite channel, leased during the most inexpensive 3 or 4 hours (less until the fifth year) of each working day will accommodate all E-COM message traffic, USPS administrative data exchange, and the distribution of new and modified customer logos and signatures. The calculations provided are for uncompressed data without error detection and correction (EDAC). Meeting the stated goals does not depend on a high data compression ratio.

We have discussed the approaches to compression of graphics data. We have presented data gathered by means of the USPS/NOSC Image Capture & Analysis System(ICAS) that shows the results of 5:1 compression in which one-dimensional variable run-length codes are used. We believe that compression ratios of 3:1 to 8:1 may be achieved, depending on the spatial frequency components of the logo image, by using a modified Huffman code and a modified READ code. For unfavorable noise statistics of the communication channels, some of this gain may be given up to provide error detection and correction (EDAC) of the transmitted data. Success in the ability to compress the data will relieve the raw channel capacity calculations we have used thus far. A portion of this study examines the retrieval of stored graphics data from local memory and recomposition into byte-size bit-map data in real time for high-speed printing at rates up to 1.5 pages per second. It was found that off-the-shelf microprocessor macromodules were not well suited for the speed and data agility requirements. Some specially designed components, peculiar to the selected compression algorithms will be required.

We conclude that although graphics compression would be very beneficial for storage and retrieval at SPO sites if high-speed retrieval hardware could be acquired, it does not significantly affect communication bandwidth.

The USPS currently uses a 7-bit American Standard for Information Interchange (ASCII) code for the transmission of text data via E-COM. This library of text, symbols, and commands consists of 128 characters of 7-bit binary words. The parity bit normally accompanying the 7-bit word is unused in E-COM. In the short time we have had to address the benefits of text compression, we have found that compression ratios of 1.35:1 to 1.4:1 seem to be about the maximum obtainable. We found no published work covering the compression of ASCII text data involving the complete set of 128 ASCII characters. Statistics are not available on the frequency of occurrence of ASCII characters in customer E-COM traffic nor in USPS administrative reporting interchange (probably vastly different). An assessment of the benefits of compression can be made only on available character probability statistics. A separate document on text compression was sent to the USPS on 24 December 1982. The present report contains only an abstract of the results.

In this document we describe a candidate logo/signature control block to be added to the E-COM message header data stream. We found that possibly as few as 56 bytes of data were necessary, and that this amount added to the estimated 1400 average bytes per message increased by only 3.95% the existing E-COM message bandwidth. With very minor modifications to the existing E-COM software, the accommodations for up to three logo/signature calls per document can be added at any time. Operating software for the production of printed customer messages may be modified to ignore the logo control statement. Test stations at two or more remote sites working from the Digital Equipment Corp (DEC) data and control buses could begin evaluating graphics as soon as even primitive communications channels are established among sites.

We discuss the digitizing of customer logos. The technical aspects of their acquisition are not complicated. Rules and procedures should be established soon.

We estimate that the two heaviest impact areas will be the inter-SPO communication modem and its interface, which will be needed more for message text than for logo data, and the formatter/controller, for preparation of text plus logo/signature data for the electronic interface to the image generator module.

To meet the forecast of 10 billion E-COM messages at the end of the fifth year at 1400 characters (bytes)/message, 20-Mb/s inter-SPO data rates will be required. Acquisition of such facilities by lease from common carriers probably should be started very soon to meet the upcoming requirements.

The second area of impact, the local logo storage and retrieval system and the printer formatter/controller needed to provide plot buffer data to existing high-speed printers, will require careful digital architectural design.

Graphics Conversion Subsystem

One of the key subsystems of the upgraded E-COM system is the graphics conversion subsystem, whose function is to provide a capability for converting customer hard-copy logos and other graphics into digital soft-copy facsimile form for cosmetic touch-up, storage, transmission, and printing. With the USPS, NOSC has produced a layout for a graphics conversion subsystem work station. Components were selected, and all equipments for the work station are on order or have been received. Principal components include the Datacopy camera and display, the Bencher copy stand, the AED 1024 color graphics terminal, and the Cambridge Digital LSI/11-based microprocessor (appendix C). The AED 1024 will accommodate the software for the framing of graphics subimages, cosmetic corrections, and the thinning algorithm. Outputs from the graphics conversion subsystem are in the form of floppy disks, streaming tapes, DEC Q-bus, and RS-232C port. Figure 1 is a block diagram of the subsystem data flow.

Delphax Printer Subsystem

A second key E-COM subsystem is the output printer and its control equipment. The USPS is expending considerable in-house effort in the evaluation of the HP 2680 laser printer. NOSC has been tasked to evaluate one of the system alternative printers, the Delphax 2460 ion deposition printer. These are both very high performance units. The printer for NOSC is being modified by Miltope, Long Island, NY, to add tractor feed, a new plot buffer, and some subsystem control software. The goals for NOSC in this area are to evaluate the performance and reliability of the printer and to provide interfaces for the E-COM text and stored logo inputs. Figure 2 is a block diagram of the Delphax printer subsystem. The principal components are the Delphax 2460 printer, an LSI-11/23, the Delphax formatter/controller, and a Winchester disk drive. The formatter/controller is expected to accommodate one-page messages with approximately 20 square inches of dissimilar logo graphics per page. In a few months Delphax and Miltope will release a new faster print and plot buffer that will allow access to the composition of larger areas of graphics while still printing at the rate of one page per second NOSC intends to acquire and evaluate the newer version when it is available.

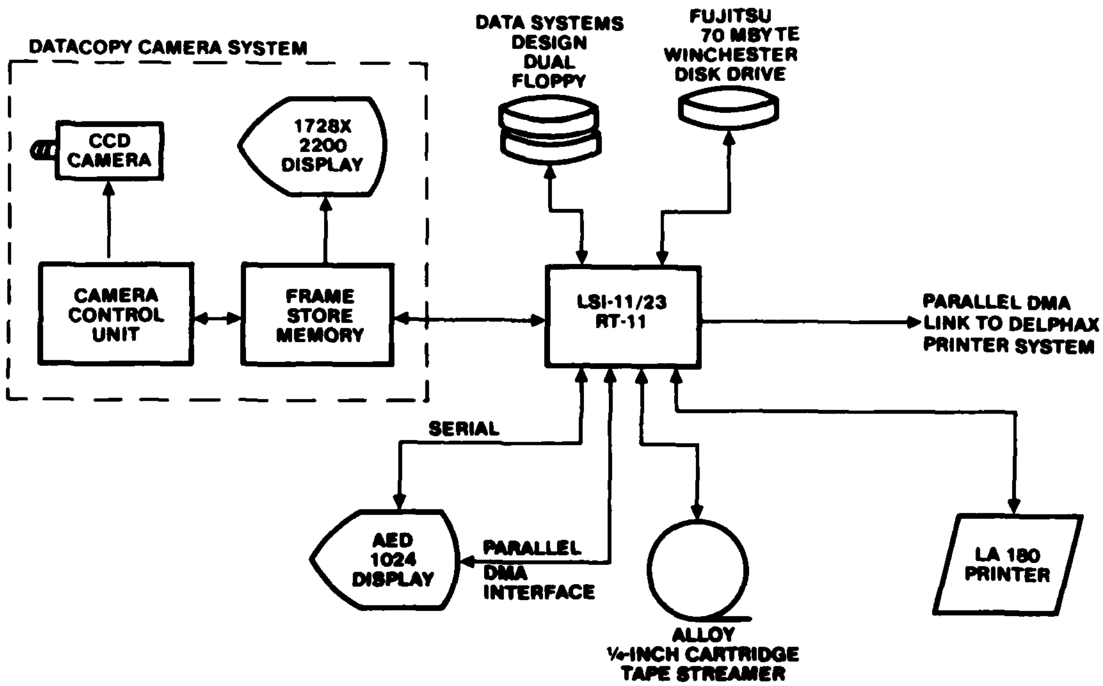


Figure 1. Graphics conversion subsystem block diagram.

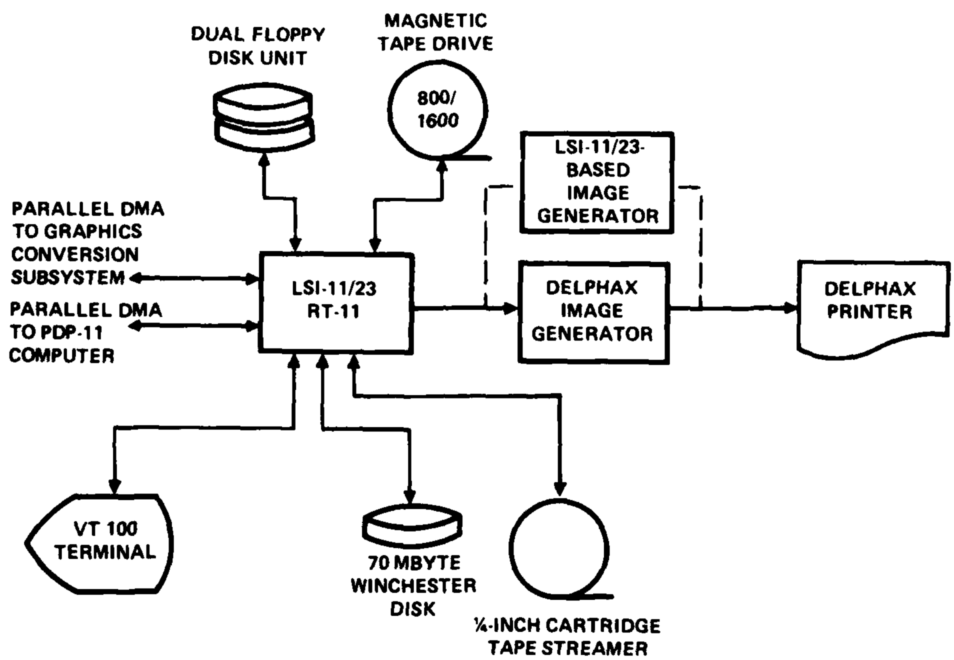


Figure 2. Delphax printer subsystem block diagram.

APPENDIX A

TEXT CHARACTER COMPRESSION STUDY

APPENDIX A CONTENTS

APPENDIX A ILLUSTRATIONS

APPENDIX A TABLES

INTRODUCTION

Character data compression has been studied and reported in the literature. An example reference is included with this report, in which a Huffman tree method is used to develop a code based on the probability of occurrence of each character in message traffic. The USPS may have two applications for character data compression: E-COM customer traffic and the USPS administrative net.

In general, two types of character data are subject to compression. The first is business-oriented files, which can contain numerous blanks or zeros. An example might be an E-COM transaction message such as a bill or invoice. The second type is simple text containing primarily alphabetical data. Since administrative traffic may be statistically high in numerical data, the distribution of character frequencies may be very different from that of E-COM customer traffic. A published "typical" character probability distribution for lowercase letters is shown in table A1.

Compression of business-oriented data by suppression of blanks, zeros, or both is routine. In fact, one author (reference A21) calls null suppression the de facto method of compressing business data files. Software for accomplishing this is available. The algorithms used are relatively simple; and the payoff, depending on the data set, can be significant.

Compression of text data, on the other hand, is not common. Algorithms for the compression of text are more complex; although various methods have been tried, compression seldom exceeds about 50% (reference A1). So far, a search for vendor-supplied text compression software has been fruitless, although there are various papers in the literature describing research in this area. (Reference A1 contains a good bibliography.)

Other methods used to compress text have included pattern substitution and Huffman coding. Pattern substitution involves replacing a string of characters with an unused symbol in the character set. Huffman coding is statistical in nature. With it, each character is assigned a code whose length varies from character to character. Compression is achieved by associating shorter codes with more frequently occurring characters.

NULL SUPPRESSION

One method of compressing zeros (or blanks) is to insert a bit map at the beginning of each record. A 1 in the bit map represents the presence of data; a 0 bit denotes a data value of zero. Only the bit map and the nonzero data are stored or transmitted (see figure A1).

Another simple method of compressing redundant data is to use a form of run-length coding. A special symbol, used to represent the redundant character, is followed by a number, which indicates the number of times that the character is repeated. For instance the record

GA0000FNTZ00000TQ

Character	Percent Usage
Space	16.4
e	10.7
t	8.2
a, o, i, n, s, r	5.7
h	4.1
d, l, u, c, m, p, f	2.5
y, w, g, b	1.6
v, k, j, x, z, q	0.4

Table A1. Frequency usage of lowercase characters.

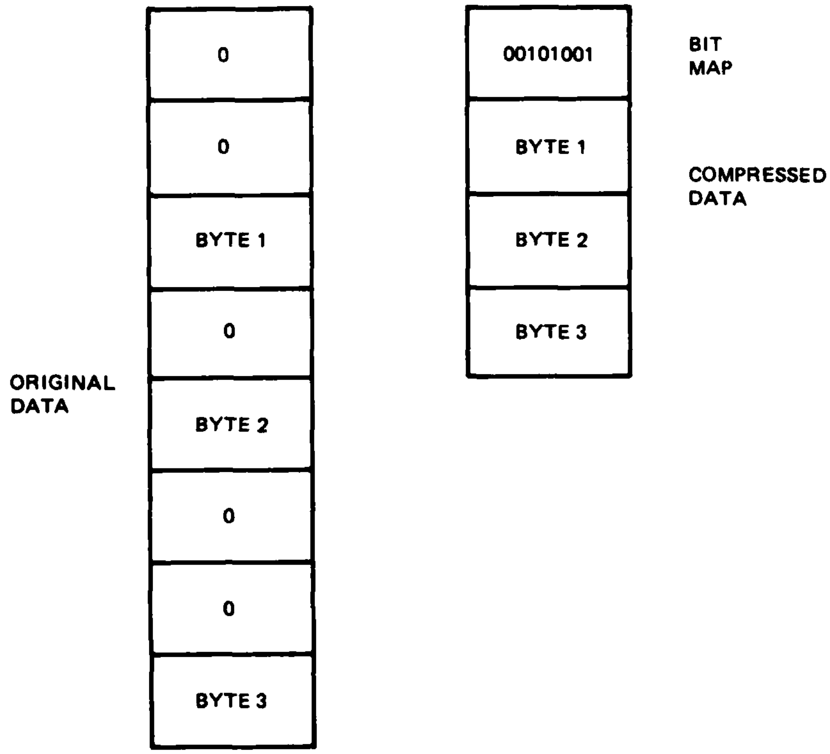


Figure A1. Null suppression with a bit map.

could be coded as

GA#4FNTZ#5TQ,   where # = 0.

A more general type of null suppression is redundancy coding, in which runs of any character, say a string of the dashes, are run-length encoded. For instance, with ASCII data, the parity bit could be used to signal that the character encoded by the other 7 bits is to be repeated. The data byte immediately following could contain the number of times that the character is to be repeated.

Several software utilities that perform null suppression have been identified. Intersystems, of Dumbarton, NH, markets a module in object form that removes blanks and/or performs encryption. It is designed for IBM machines and sells for $850 for the first licensing. DATAPACK is a redundancy-encoding utility sold by Circle Software, of Downers Road, IL. It uses a "downstream" technique to encode data. As data are written to disk or tape, the utility searches for redundant characters. Redundant data that are found are rewritten in compressed form. DATAPACK is in use at Aspen Systems Corp, Rockville, MD, where compression has ranged from 13% for very dense text to 60% for sparser data types. When used in an on-line mode, the impact on I/O time has been found to be insignificant. This utility is also designed for IBM machines and costs $4000 for the first license. Other software packages that compress by supressing nulls are found in the DATAPRO software catalogue.

PATTERN SUBSTITUTION

Here, the most frequently occurring sets of characters are assigned unused codes. The method of Snyderman and Hunt (reference A27) uses pairs of characters. The first character is called the "master character" (blank, a e, i, o, u, n, t) and the second is referred to as a "combining character" (blank, and all lowercase except j, k, g, x, y, z). The process starts by placing two bytes in a shift register. If the first byte is not a master character or if the second byte is not a combining character, then the first byte is shifted out as is and a new byte is entered. If a pair is detected, the first byte is rewritten with the code for that pair and shifted out and, two new bytes are shifted in. This method is relatively simple, and its output is fixed-length fields (bytes). Compression and decompression were found to take about 70 ms per 1000 uncompressed characters with an IBM 360. Compression was about 30%.

Longer patterns such as text fragments were used by Schuegraf and Heaps (reference A24) to achieve slightly greater compression. However, processor loading increases drastically as comparisons between the data and the pattern table increase in number.

HUFFMAN CODING

Higher compression levels can be achieved by exploiting the statistical properties of the character set. The Huffman coding algorithm uses a table of probabilities of occurrence for each symbol to generate a code word for each.

Thus, any Huffman code is a function of the statistics of the data set upon which it is trained. Its efficiency, when encoding another data set, may be less. (However, the frequency of occurrence of letters in English text has been shown to be relatively constant across various sample blocks of text.) With this coding technique, relatively high compression (about 1.5:1) has been achieved on symbol sets containing single-case alphanumerics and a few special characters. Huffman code implementation is relatively complex, however, and its output, unlike the other methods described, is a variable length code which further complicates software.

Some preliminary calculations have been made by using published frequencies of usage for the 26 letters of the alphabet. Unfortunately, the data we were able to locate consist only of lowercase characters and does not include uppercase characters, spaces, digits, or punctuation. There is a typing rule of thumb, however, which states that the average word length is five characters, implying that spaces account for one sixth of all characters. To use these data, we added the 20 percent for spaces and renormalized to 100, yielding the percentages in table A1.

CLASSICAL HUFFMAN CODING

A basic measure of the potential compressibility of a data set is its entropy. Let the characters of the set

$$X = (x_1, x_2, \ldots , x_i, \ldots, x_M)$$

each have a probability of occurrence p_i and be represented by a code word of n_i bits. The entropy, H(X), of the set is defined as

$$H(X) = (p_i) \log_2 (p_i) \ .$$

The Noiseless Coding theorem states that the minimum average code word length,

$$\bar{n}_i = \Sigma \ (n_i)(p_i),$$

is bounded by the entropy of the set. That is,

$$\bar{n}_i \leq H(X),$$

where the inequality applies only if each p_i is a reciprocal power of 2. A measure of the effectiveness of a coding scheme is then the degree to which the average code length approaches the entropy of the set.

As an example, consider two character sets, X_a and X_b, each having four symbols, x_1, x_2, x_3, and x_4.

	X_a		X_b	
	p_i	Huffman Code	p_i	Huffman Code
x_1	1/2	1	1/4	11
x_2	1/4	01	1/4	10
x_3	1/8	001	1/4	01
x_4	1/8	000	1/4	00

$\overline{n_i} = 14/8$ $\overline{n_i} = 16/8$

The entropy of set X_a is:

$$H(X_a) = -(1/2) \log_2 (1/2) - (1/4) \log_2 (1/4) - (2)(1/8) \log_2 (1/8)$$
$$= 14/8,$$

while

$$H(X_b) = 16/8.$$

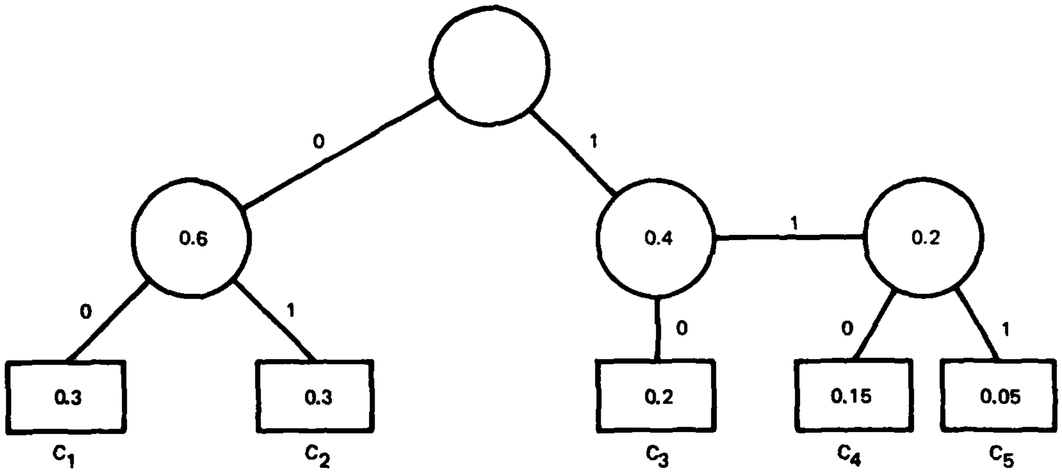
Thus, some compressibility of set X_a could be expected. However, data set X_b is incompressible since 2 is just the uncompressed number of bits needed to represent the four symbols of X_b. The uniform distribution of the characters of X_b represents a worst-case distribution for Huffman coding. The average code word length, n_i, for set X_a equals the theoretical minimum $H(X_a)$ because the p_i of X_a are reciprocals of powers of two.

The Huffman code is optional in the sense that symbols of the data set cannot be represented with a smaller average number of bits. If the probabilities of occurrence are reciprocal powers of two, as in the example, then n_i will equal the theoretical limit H(x). If this is not so, then n_i will, by another theorem, be within one bit of H(X). That is, for a Huffman code,

$$H(X) \leq n_i < H(X) + 1 \quad .$$

In addition, Huffman codes are uniquely decipherable, having what is called the prefix quality. This means that no code word is a prefix of another code word.

The Huffman code is synthesized as follows (see figure A2, taken from reference A1). The symbols of the character set are considered as terminal nodes of a binary tree. A probability of occurrence is associated with each



HUFFMAN CODE FOR EACH OF THE CHARACTERS

CHARACTER	CODE
c_1	00
c_2	01
c_3	10
c_4	110
c_5	111

Figure A2. Synthesis of a Huffman code.

node. Two of the nodes having the lowest probabilities are linked to form another node whose probability is the sum of its two descendents. A 0 is associated with one path to the new node and a 1 with the other. The new node now replaces its two descendents and the process is repeated until a single root node remains. The Huffman code, from left to right, for each character is the bit value encountered when moving through the tree from the root node to the corresponding descendent node.

Usually only single characters are subjected to Huffman coding. Higher performance can be obtained by encoding character patterns as well. Doing this takes advantage of the correlation between the occurrence of various combinations of characters but adds even more complexity. Reference A1 discusses the results.

HYBRID HUFFMAN CODING

As an alternative to the classical approach to Huffman coding, a combination of the straight Huffman algorithm and a sort of "shift" code and straight 7-bit character representation was used. The most frequently used 9 characters are assigned their individual probabilities while the remaining 117 characters are grouped into an "other" category. Each character (or group) is then assigned a code by using the Huffman technique in figure A3. Because the "other" group accounts for 30 percent of usage, it is assigned the shortest code (00). Each character within the "other" group is then given the code 00xxxxxxx, where the x's are the original ASCII character codes. The other nine characters are assigned the codes shown in figure A3. The reasoning behind this approach is that the two bits added 30 percent of the time will be greatly outweighed by the 3- or 4-bit savings from the other 70 percent. The calculated compression ratio for this method is about 1.35:1, as shown in figure A4.

Two significant problems are associated with this approach. First, all frequencies are based upon published data for which the source of the frequency calculations is not available. It is, therefore, highly probable that those values bear little, if any, relationship to E-COM traffic, especially on the administrative net. As a result, actual compression ratios could be higher or lower, depending on the actual data. It should be noted that the hybrid Huffman approach would be less sensitive than the classical approach to detracting redistributions because of the maximum 9-bit code length. Actual data could cause an overwhelming number of 10- to 14-bit codes to be used in the variable-length (classical) code method, however.

The second problem hinges on the fact that the compressibility calculations do not take into account the overhead that must be added to compressed data. In uncompressed data, relatively simple error detection and correction are required. With any variable-length code, however, overhead is required to allow the data to be resynchronized if a transmission error causes invalid codes to be interpreted by the receiver. The overhead, then, will necessarily reduce the effective overall compression ratio.

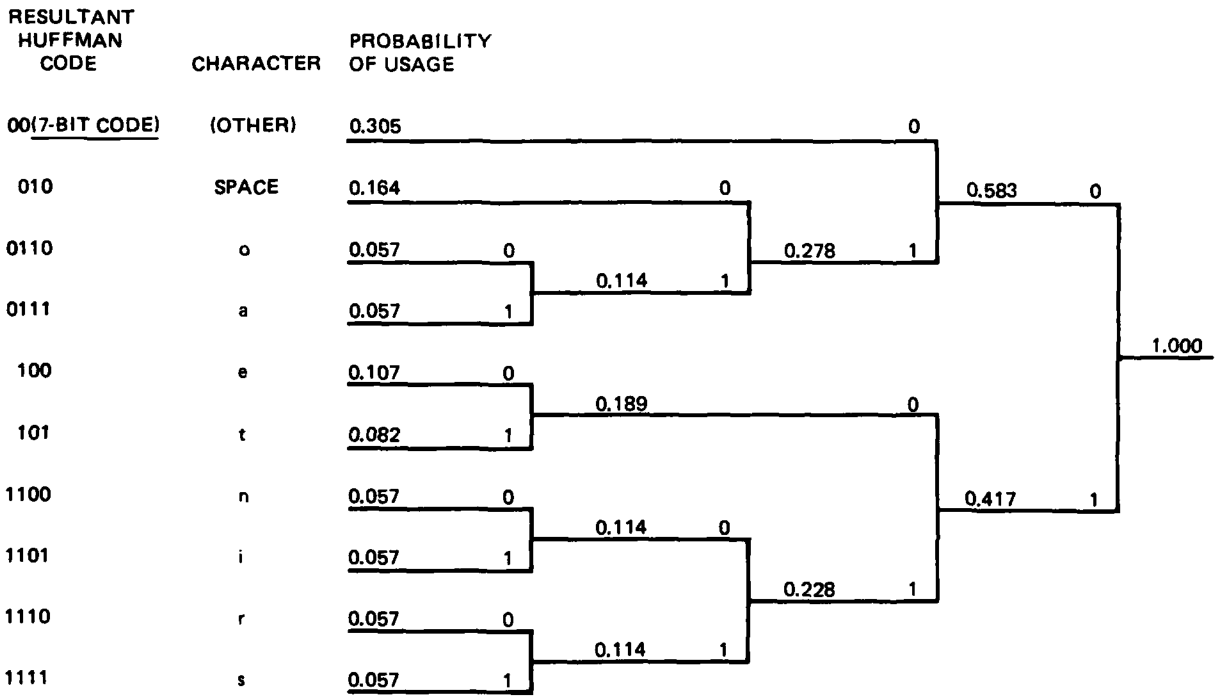


Figure A3. Hybrid Huffman code.

CHARACTER GROUP	PERCENTAGE	NUMBER OF BITS PER CHARACTER
OTHER	0.305	9
SPACE e t	0.353	3
o a n i r s	0.342	4

THIS YIELDS AN AVERAGE OF 5.172 BITS PER CHARACTER, WHICH IN TURN GIVES A COMPRESSION RATIO OF 1.35:1, BASED ON 7 BITS PER CHARACTER UNCOMPRESSED.

Figure A4. Compression ratios for hybrid Huffman code.

ALTERNATE COMPRESSION METHODS

The Baudot code was developed by Emile Baudot in the early days of telecommunications. It is a 5-bit code with two shift characters: shift-up and shift-down. A shift-up (shift-down) code signals that all character codes to follow are from the uppercase (lowercase) set of characters. Thus $(2^5 - 2)2$ or 60 characters can be encoded with this 5-bit code.

Compression ratios obtained by modified Huffman codes yield savings of approximately 1.35:1 to 1.4:1. This saving of 7-bit code length results in a length approximately equivalent to 7 divided by 1.4, thus a 5-bit code. Therefore we must look at codes of 5 bits or less to find competition for the Huffman approach.

Table A2 presents a 5-bit code using a Baudot-like subset selection scheme. By reserving the first three character codes as address pointers (shifters) rather than characters, it is possible to transfer the encoder/decoders internal state from its present internal state (resident character column) to four (or more) alternate states, each recognizing an arbitrarily assignable 29-character subset of the ASCII code.

Table A2 shows the 00000 address, probably the proper default code for starting a message (unless the $ is always first), containing the capital characters plus space, period, and comma. The address 00001 contains the same information in lowercase. A third state column contains the numerals, math, and accounting symbols, plus space, period, and comma.

The fourth and fifth state columns contain the remainder of the 128-character ASCII set plus some duplicates. Since there are 145 character spaces in the five 29-character columns, there is room for some duplication between columns in the 145-character set. It should be mentioned that it takes two consecutive address codes such as 00001 followed by 00010 to enter the less frequently used columns.

The overhead for a scheme of this type is generated when there are state changes or transfers from column to column. For example, starting a sentence with a capital letter, code 00000, followed by lowercase text, code 00001, adds 5 bits to the data stream overhead. If the sentence ends with a question mark or has colons or semicolons, then a 5-bit state change to fetch the punctuation mark and a 5-bit code to get back to lowercase letters may be required.

Since a perfect 5-bit no-overhead code is equivalent to a Huffman compression ratio of 1.4 on the ASCII 7-bit set, there will be some increase in the average number of bits required per character. This disadvantage may be offset by the appreciable advantages of using a fixed-length code.

With fixed-length codes, an error bit affects only a single character unless bit sync is lost, which is unlikely. Customers may accept an occasional character error in context unless it is a number ($), whereas spelling out or repeating of number groups may be required if the system bit-error rate is high.

Table A3 shows a partially populated 4-bit state table that accommodates 3 addresses and 13 character codes per column. The 15 columns of 13 characters each provide for 195 character spaces. With the 4-bit code, the probability of continuing a text character sequence in the same column (state) decreases and overhead 4-bit state-changing addresses are required more frequently.

Additional statistical information as to the frequency of occurrence of characters in the message stream is required for properly populating compression tables A2 and A3. Character codes must be grouped to minimize the changing of character columns. True statistical data on the needed probabilities for formally completing the chart are probably nonexistent. Good intuitive reasoning for designing the codes may provide assignments that come close to equaling the performance of a formally populated compressor/ decompressor.

Subset Address Codes	00000 00001 00010	00000	00001	00010	00000 00001	00001 00010
	3	A	a	0	DLE	NUL
	4	B	b	1	DC1	SOH
	5	C	c	2	DC2	STX
	6	D	d	3	DC3	EXT
	7	E	e	4	DC4	EOT
Available Character Code Space*	8	F	f	5	NAK	ENQ
	9	G	g	6	SYN	ACK
	10	H	h	7	ETB	BEL
	11	I	i	8	CAN	BS
	12	J	j	9	EM	HT
	13	K	k	$	SUB	LF
	14	L	l	#	EOC	VT
	15	M	m	%	FS	FF
	16	N	n	+	GS	CR
	17	O	o	–	RS	SO
	18	P	p	=	US	SI
	19	Q	q	|	&	_
	20	R	r	@	*	]
	21	S	s	:	!	[
	22	T	t	(	/	^
	23	U	u	)	;	{
	24	V	v	/	?	}
	25	W	w	&	"	:
	26	X	x	CR	CR	/
	27	Y	y	HT	HT	'
	28	Z	z	LF	LF	—
	29	space	space	space	space	space
	30	period	period	period	period	HT
	31	comma	comma	comma	comma	LF

*29 x 5 = 145 spaces

Table A2. Sample 5-bit character compression code.

Subset Address Codes	0000 0001 0010	0000	0001	0010	0000 0001	0000 0010	0001 0010	0001 0000	0010 0000	0010 0001	0000 0001 0010	0000 0010 0001	0001 0000 0010	0001 0010 0000	0010 0000 0001	0010 0001 0000
Available Character Code Space*	3	a	n	A	N	1	!	1/4	DLE	NUL	etc.					
	4	b	o	B	O	2	@	1/2								
	5	c	p	C	P	3	#	;								
	6	d	q	D	Q	4	$	'								
	7	e	r	E	R	5	%	/								
	8	f	s	F	S	6	¢	:								
	9	g	t	G	T	7	&	"		FILL IN FOR MAXIMUM CHARACTER SEQUENCE RETENTION IN A SINGLE COLUMN						
	10	h	u	H	U	8	*	?								
	11	i	v	I	V	9	(									
	12	j	w	J	W	0	)									
	13	k	x	K	X	spc.	—									
	14	l	y	L	Y	per.	+									
	15	m	z	M	Z	com.	=									

*13 x 15 = 195 spaces

Table A3. Sample 4-bit character compression code.

SOFTWARE AVAILABILITY

A search was conducted for commercially available software packages that compress textual data by pattern substitution or Huffman coding. None were found, but Circle Software is said to be developing a utility for text compression by Huffman coding, to be available in 1984. Its use is expected to have a significant impact on I/O time.

The National Bureau of Standards Institute of Computer Science and Technology was contacted. Although they are involved in a wide range of standardization issues related to computer science, they apparently have no interest in text compression.

TEXT COMPRESSION COST SAVINGS

During a discussion of text compression at USPS, NOSC was requested to review briefly the economics of text compression. The following example uses assumed load factors and real landline communication channel costs. It is a very simplistic model, but it addresses some of the tradeoffs involved in making a decision regarding the use of text compression.

In accordance with the NOSC assumptions, calculations show that message traffic between LA (super-SPO) and Phoenix (mini-SPO) is half the average traffic (see appendix B), and that 64 000 messages a day are received from customers and delivered to customers at the end of the first year at Phoenix. By equation 1 from reference A6:

$$T = 6.552 \times 10^3 \times \frac{D}{B} ,$$

where

T = total transmission time in seconds

D = daily messages transmitted

B = communication bandwidth in b/s.

Rearranging to solve for B,

$$B = 6.552 \times 10^3 \times \frac{D}{T} .$$

Assuming that D', the subset of D that is destined for LA from Phoenix is 1/24th of the inter-SPO Phoenix traffic, i.e.

$$D' = \frac{D}{24} = \frac{6.4 \times 10^4 \text{ messages/day}}{24} = 2667 \text{ messages/day},$$

then the required bandwidth for the daily interchange is

$$B = 6.552 \times 10^3 \times \frac{2667}{24\ h} \times \frac{h}{3600\ s} = 203\ b/s.$$

Using the same line in the half-duplex mode for two-way traffic doubles the bandwidth to 406 b/s. Assuming that the traffic will increase tenfold in 5 years, the required bandwidth will be 4060 b/s. A two-to-one peak to average transmission of 8120 b/s can also be accommodated by using a 9.6-Kb/s line without compression.

For a 10:1 peak to average traffic ratio, 4.2 (must round up to 5) lines may be required at a time for periods up to 2.4 hours. Character compression will reduce the communication channel demands during this 10:1 peak load at the end of year 1987 by a ratio of 1.35:1. This will require 3.1 (must round up to 4) lines at 9.6 Kb/s. Thus compression could save the use of one 9.6-Kb/s line for 2.4 hours/day. If the hourly cost per 9.6-Kb/s line is a linear fraction of the 24-hour-per-day cost, then it can be calculated as follows:

$$\frac{\$\ 1364.60^*}{\text{month}} \ @\ \frac{24\ \text{hours}}{\text{day}} = \frac{\$56.86}{\text{month}} \ @\ \frac{1\ \text{hour}}{\text{day}} \quad \text{(per 9600-b/s line)}$$

Uncompressed data requires five lines during peaks whereas compressed data requires four. If all data are sent at 10 times the average rate, then all the data are transmitted in less than 2.4 hours. This would result in savings as follows:

$$\text{savings} = \frac{\$56.86/\text{month}}{(\text{hours/day})} \times 2.4\ \text{hours/day}$$

$$= \$\ 136.46/\text{month}$$

$$= \$1637.52/\text{year}$$

The technical requirements for the text compressor/decompressor can be summarized as follows:

Each unit must accommodate from 1 to 5 9600-b/s inputs/outputs.

Each unit must operate as a text compressor and decompressor.

If the 2.4-hour simplex mode for each direction of traffic is unsatisfactorily long, then the compressor/decompressor must operate in the full-duplex mode to reduce the two-way transmission time by a factor of two.

---

* Cost furnished by Auger, USPS, Rockville, MD.

Text compressors are required in pairs, one at each end of each inter-SPO trunk.

As an alternative to the first requirement listed above, it may be more practical from a cost standpoint under peak load conditions to switch to a 56 Kb/s line, if one is available. If this is done, then the compressor/decompressor must also accommodate a 56-Kb/s I/O data stream.

No known text compressor/decompressor could be located during this study that meets the above requirements. In fact, no off-the-shelf equipments or components to transmit the full ASCII character set in any compressed form have been located.

The annual saving of this hypothetical link as the result of character compression amounts to $1637.52. Over 5 years this totals $8188. If compressors could be procured in USPS quantities for $4094 ($8188/pair) including 5-year maintenance provisions, the compression/decompression process would produce break-even costs. At the end of the fifth year the equipment may become obsolete as the result of expanding message traffic loads. Text compression and decompression does not, therefore, appear to offer any clear-cut advantages to E-COM.

The preceding example greatly oversimplifies the tradeoffs needed for assessing the true benefits of text compression for E-COM. The costs of microprocessors that may be capable of compressing and decompressing text at the required rates are continuing to fall rapidly on the off-the-shelf market. A small processor that can be placed in series between the modem and the printer unit may be available at an affordable cost. It is intended that a more detailed analysis of text compression be made before text communication channels are required for E-COM.

CONCLUSIONS OF APPENDIX A

Data compression offers the hope of decreased storage and communication costs. However, it can introduce programming and formatting complexity and impact central processor loading, thereby increasing system cost. The decision to adopt compression must weigh these two classes of costs.

Compression is suitable for large mass storage and for communications. Compression is more practical for randomly accessed disk files than for sequentially accessed tape files. On sequential runs when I/O is blocked, the impact on I/O time can be significant. The feasibility of compression depends on the data. Files with an abundance of zeros and blanks are good candidates.

Table A4 compares the compression schemes discussed. Null suppression is a simple and relatively efficient method of compressing data containing blanks and zeros. It may be a candidate for compressing certain types of E-COM messages such as administrative traffic or transaction correspondence.

Text compression by Huffman coding or other methods is not a mainstream data processing activity. It simply has not yet arrived. Its incorporation into E-COM would require a software development effort of some magnitude. Although it appears that some compression of text--on the order of 1.5:1--is possible, its impact on system throughput is more difficult to evaluate.

Technique	Complexity	Compression Ratio	Code Words Available	Software
Null suppression	Low	Good for data with runs of blanks & zeros	bytes	Yes
Redundancy coding	Low	Good for data with runs of blanks & zeros	bytes	Yes
Pattern substitition (2 character)	Moderate	1.3	bytes	No
Baudot-like coding	Moderate	1.3	fixed word lengths	No
Huffman coding	High	1.5*	variable-length strings	No
Huffman coding w/patterns	Highest	2.0	variable-length strings	No

*For a character set limited to single-case alphas and a few punctuation marks.

Table A4. Summary comparison of text compression methods.

CHARACTER DATA COMPRESSION REFERENCE INDEX

Subject	Reference Number
Overviews	A1, A18, A20, A21
Bigram	A3, A7, A22, A27
N-gram	A2, A4, A5, A12, A15, A17, A23, A24, A30, A31
Prefix	A19
Word	A29
Phrases	A25
Huffman	A6, A8, A26
Block	A13
Numerical	A10, A11, A28
Run length	A14
General	A9, A16, A32

CHARACTER DATA COMPRESSION BIBLIOGRAPHY

A1. Aronson, J. — Data Compression - A Comparison of Methods. National Bureau of Standards - June 1977, NBS Special Pub 500-12.

This is a good overview. It contains a tutorial on Huffman coding.

A2. Barton, I.J. et al. — An Information - Theoretic Approach to Text Searching in Direct Access Systems, Comm. 4 ACM, Vol 17-6, p 345.

Describes the selection of equi-probable variable length character strings for use as keys for direct access to a data base.

A3. Bookstein, A. — A Mathematical Model for Estimating the Effectiveness of Bigram Coding. Info. Mag. & Proc., Vol 12, p 111.

Examines the relation of bigram overlap to bigram coding effectiveness. Good!!!

A4. Claire, A.C. et al. — Character Strings in a Natural Language Data Base. Computer Journal, Vol 15-3, p 259.

Discusses selection of equi-probable variable length n-grams.

A5. Cooper, D. et al. — Compression of Wiswesser Line Notations Using Variety Generation. J. Chem. Inf. & Computer Science, Vol 193, p 165.

Describes an algorithm for selection of variable length n-grams.

A6. Corbin, H. — An Intro to Data Compression. Byte, April 1981, p 218.

Describes and lists program for Huffman coding and decoding.

A7. Cortesi, D. — An Effective Text-Compression Algorithm. Byte, Jan, 1982, p 397.

Describes a simple method for encoding bigrams. Neat!!!

A8. Grappel, R.D. — Instruction Set Makes a μP's Job Easier. EDN Nov., 1982, p 145.

Example of use of a μP for Huffman coding.

A9. Grignetti, M.C. — A Note on the Entropy of Words in Printed English. Info & Control, Vol 7, p 304. 1964.

Calculates word entropy to be 9.83 bits using an approximation to Zipf distribution.

A10. Hagamen, W.D. et al. — Encoding Verbal Information as Unique Numbers. IBM Systems J., Vol 4, 1972, p 278.

Describes encoding of runs of characters as numbers.

A11. Hahn, B. — A New Technique for Compression and Storage of Data. Comm of ACM, Aug 1974, Vol 17-8, p 434.

Same as 9 except more compression oriented.

A12. Lea, R.M. — Text Compression with an Associative Parallel Processor. Computer Journal, Vol 21-1, p 45.

N-gram encoding with hardware. Uses method of Clare (1972) & Lynch (1979).

A13. Ling, H. — Block Oriented Information Compression. IBM J. Res. & Develop., March, 1975, p 141.

Uses Mathematical System Theory to eliminate linearly dependent data in a block to achieve compression. Does not need prior knowledge of data statistics.

A14. Lynch, M.F. — Compression of Bibliographic Files Using an Adaption of Run-Length Coding. Inform. Stor Retr., Vol 9, p 207.

Character and bigram codes are selected which facilitate run length coding of zeros.

A15. Lynch, M. F. — Analysis of the Microstructure of Titles in the Inspect Data-Base. Inform. Stor. & Retr., Vol 9, p 331.

Contains a description of an algorithm for extracting equifrequent n-grams.

A16. Marron, B.A. et al. — Automatic Data Compression. Comm of ACM. Vol 10-11, 1967, p 711.

The method used here is not obvious.

A17. Mayne, A. — Title unknown. Computer Journal, Vol 18-2, p 157.

Contains a good discussion of creation of an n-gram list.

A18. Peterson, J.L. — Text Compression. Byte, Dec., 1974, p 106.

Light discussion of some standard compression techniques.

A19. Radhakrishnan, T. — Selection of Prefix & Postfix Work Fragments for Data Compression, Info. Proc. & Manag., Vol 14, p 97, 1978.

Good description of algorithm to do above as well as a sorting algorithm.

A20. Reghbati, H.K. — An Overview of Data Compression Techniques. IEEE Trans. Computers, April 1981, p 71.

Superficial

A21. Ruth & Kreutzer — Data compression for large business files. Datamation, Sept 1972, p 62.

A brief overview of some compression schemes and a description of a system used at the Navy Fleet

Material Support Office for compression of inventory records. It uses Huffman coding of characters and runs of blanks and zeros. Contains a good discussion of system issues.

A22. Schieber, W.D. — An Algorithm for Compaction of Alphanumeric Data. J. of Library Automation. Vol 4-4, Dec, 1971, p 198.

Discusses use of bigrams.

A23. Schuegraf, E.F. and Heaps, H.S. — Selection of Equifrequent Word Fragments for Information Retrievel. Inform. Stor. & Retr., Vol 9, p 697.

Describes in detail an algorithm to do above.

A24. Schuegraf & Heaps — A Comparison of Algorithms for Data Base Compression by the Use of Fragments as Language Elements. Infor. Stor. Retr., 10 (1974) pp 309-319.

Describes in detail an algorithm to do above.

A25. Schwartz, E.S. — A Language Element for Compression Coding. Information & Control, Vol 10, p 315, 1967.

This explores redundancy in words and the use of phrases as code elements. Abstract and not too useful.

A26. Sellers, J — Generate Huffman Codes. Byte, July 1982.

A program (listing) to do above.

A27. Snyderman & Hunt — The Myriad Virtues of Text Compression. Datamation, December, 1970.

Describes an algorithm and program for compacting EBCDIC coded characters by coding character pairs as unused EBCDIC codes.

A28. Ting, T.C. — Compacting Homogeneous Text for Minimizing Storage Space. Int. J. Computer & Information Sciences, Vol 6-3, 1977, p 211.

Discusses multiple-level coding of character words, field, etc., where each code word is a digit in a number system to base n and where n is the size of the list. Does not appear to be useful.

A29. Tropper, R. — Binary Coded Text: A Text Compression Method. Byte, April, 1982, p 398.

Discusses encoding text using dictionaries of 1000 most common root words and 16 most common word endings.

A30. Wagner, R.A. Common Phrases and Minimum-Space Text Storage. Comm of ACM, March 1973, Vol 16-3, p 148.

An algorithm for optimal parsing of diagnostic messages from a computer.

A31. Wolff, J.B. Recoding of National Language for Economy of Transmission or Storage. The Computer Journal, Vol 21-1, p 42, Feb 1978.

Another algorithm for parsing text into text fragments.

A32. Weiss, F. et al. A Word Based Compression Technique for Text Files. J. of Library Automation, Vol 11-2, June 1978, p 42.

Describes a two-byte word-based coding technique.

ANNEX 1 TO APPENDIX A

CANDIDATE TEXT ENCODING TECHNIQUES

FOR

CHARACTER DATA COMPRESSION

ANNEX 1 (APPENDIX A) CONTENTS

HUFFMAN CODING

Variable length code

More frequent characters assigned shorter codes

Average no bits/char $\geq$ entropy + 1

$$\text{Entropy} = \sum p_i \log p_i$$

Optimal code for uncorrelated symbol set

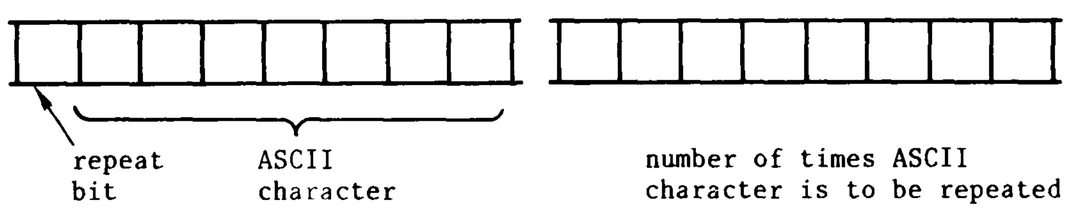
Could lose if statistics of data set not same as sample set used to generate code

Encoding and decoding relatively complex

CHARACTER RUN LENGTH ENCODING

Encode number of times a character is repeated

Example:



Simple

Could be effective in blocks containing many blanks or nulls

BIGRAM CODING

Unused codes used to encode common character pairs

Simple, byte-oriented

30% - 40% Compression

Strategies

1	X	X	X	X	Y	Y	Y

indicates bigram coding

XXXX 1 of 13 most common characters

(space) e t a o i n s h r d l u

YYY 1 of 8 most common characters

(space) e t a o i n s

Select bigrams on basis of frequency and degree of overlap

post

use of "po" as bigram prevents use of "os" as bigram

Unused control characters could also be used to encode bigrams so total set number = 128

N-GRAM CODING

Text parsed into variable length character strings (N-grams)

one length, say 8

N-grams chosen to be nearly equi-probable

Fixed length code

"Any change in character set which tends to equalize the probability of occurrences increases the information content of the message."

Original Symbol Set		Modified Symbol Set	
(blank)	15%	e (blank)	5%
e	10%	(blank) t	5%
t	5%	e t	5%
a	"	"	"
"	"	"	"

Selection of N-grams can be involved

Coding could be CPU intensive

PREFIX AND POSTFIX CODING

Subset of N-gram coding

Example:

1	X	Y	Y	Y	Y	Y	Y

indicates prefix of postfix coding

X = 1 use prefix dictionary
0 use postfix dictionary

YYYYYY = dictionary address

WORD CODING

Word occurrence in text has a hyperbolic distribution

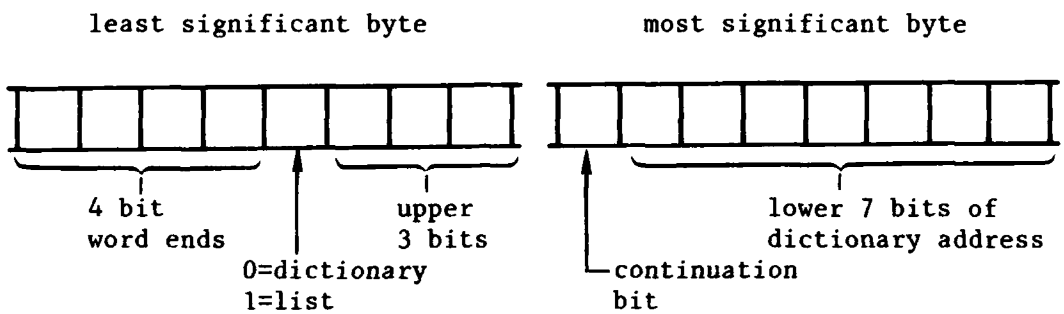
p_i = constant/i where i is rank of word in list ordered by frequency of occurrence.

Much word redundancy in text

In sample of 1 million words:

"the" accounted for 7%
100 most frequent words accounted for 50%.

Sample method



Word Ends	List	Dictionary	
ments	from words	1	punctuation and common occurrences i.e. (period, blank, blank)
ings	not found in	2	
ion	dictionary	3	
		24	
		25	1000 most common words
		26	
		1024	

High compression of homogeneous text

Complex

NUMERICAL CODING

String of characters L long represented as number to base B

Example: Encode strings 3 long to base 6

$$L = 3, \; B = 6$$

$$\text{aut} = (1)6^2 + 3(6)^1 + 4(6)^0$$

$$\text{ar} = \text{a(escape)r}$$

$$= (1)6^2 + (0)6^1 + (1)6^0$$

Dictionary

0	(escape)
1	a
2	o
3	u
4	t
5	z
6	(escape)
7	r
8	s
:	:
11	w

Constraint: for 32-bit (per word) machine

$$B^L + B^{(L-1)} + \ldots + B \leq 2^{31} - 1$$

Can be optimized by adjusting L or B

Requires computation

BAUDOT-LIKE CODING

Original

5-bit code with shift-up and shift-down character

2 character sets

Total of $2 \times (32 - 2)$ or 60 characters

Modification for ASCII

6-bit code, 2 character sets

Could use unused control codes for shift up and down

MULTILEVEL DICTIONARIES

Example: 8 dictionaries, 16 entries per dictionary, 4-bit codes

Dictionary	A	B1	B2	B3	C1	C2	C3	C4
0	blank	u	.	.	.	.	.	.
1	zero	z	.	.	.	.	.	.
2	null	w	.	.	.	.	.	.
3	e		t	.	.	.	.	*
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
12	o	.	.	C1	.	.	.	.
13	B1	.	.	C2	.	.	.	.
14	B2	.	.	C3	.	.	.	.
15	B3	.	.	C4	.	.	.	.

B1, B2, B3, C1, C2, C3, C4 in dictionary mean escape to corresponding dictionary.

e = 3	(4 bits)
w = 13, 2	(8 bits)
* = 15, 14, 3	(12 bits)

Hit in dictionary A	2:1	compression	- WIN
B	1:1		- DRAW
C	2:3		- LOSE

Efficiency of such schemes could be computed analytically given frequency of occurrence statistics

CODING SUMMARY

Huffman	Data dependent (could lose), complex, variable-length code, well known
Run Length	Simple, possible significant file compression
Bigram	Simple, possible moderate text compression
N-gram, word, prefix	Complex to design, encode, decode
Numerical	Requires significant computation
Baudot-like	6-bit code words
Multilevel dictionary	4-bit code words, simple, easy to design

COMPRESSION ISSUES

Performance: compression ratio

Dependence on message statistics

Statistics of correspondence messages different from those of transaction message

Some compression schemes can cause net loss in compression if data not as expected

Complexity: CPU time required to encode and decode

Data structure

Is 512-byte block to be maintained?

Where in data flow should messages be compressed and decompressed

Compression in hardware or software

Cost to compress & decompress vs storage & communication savings

PROPOSED CHARACTER DATA COMPRESSION STUDIES

With E-COM character frequency statistics

Compute compression using Huffman coding, Baudot-like coding, and coding with multilevel dictionary.

With E-COM dummy message tape

Determine compression from run-length coding

Design a dictionary of 128 most frequent bigrams, selected to minimize overlap, and compute compression.

For each of the above methods, determine how compression is degraded by various message types, i.e., transaction messages.

Study relationship between data compression and the constraint imposed by 512-byte data blocks for the above compression schemes. Suggest possible restructuring of data.

Implement above compression schemes on the NOSC PDP 11/70, using assembly language where appropriate. Compare run times for compression and decompression for each method.

APPENDIX B

USPS E-COM LOGO STUDY

by

Code 7323

APPENDIX B CONTENTS

APPENDIX B CONTENTS (CONTINUED)

APPENDIX B ILLUSTRATIONS

APPENDIX B TABLES

1 INTRODUCTION

The USPS R&D Laboratories, Rockville, MD, have sponsored an image acquisition and processing project at NOSC for a number of years. This technology transfer program has supported the USPS in high-speed image capture, image compression, storage and related areas. Recently, the USPS requested NOSC to assist in the study of problems related to the USPS Electronic Computer Originated Mail (E-COM) System. In particular, a study of alternatives for upgrading the E-COM system to include logos and other graphics in transmitted messages was requested.

1.1 E-COM SYSTEM

The current E-COM system began service on 4 January 1982. It allows subscribers to submit one- or two-page messages to a Serving Post Office (SPO) via a dial-up or dedicated telecommunications channel. There are 25 SPOs throughout the country. At the SPO, the messages are input to the user communications subsystem. This LSI 11/23 based subsystem simply records the messages as they arrive on intra-SPO magnetic tapes. The tapes are then transferred to the main processing subsystem, a PDP-11/44 minicomputer with tape and disk drives. The main processing subsystem reads the intra-SPO tapes and sorts messages into ZIP code designated queues residing on disk files. The messages are next sent to one of several Printronix web-feed printers, where they are printed in ZIP code order. The stacks of printed messages are then hand carried to a Bell & Howell cutter-folder-enveloper. The ZIP-sorted mail pieces finally are entered into the first-class mail stream at the SPO.

At each SPO there is also a backup subsystem that is identical to the main processing subsystem. Both of these can perform the function of the user communications subsystem. Thus the SPO is tolerant to the failure of any single component.

It is felt that sales of the E-COM service will be enhanced if company logos can be added to the message format. The service would also be more attractive if signatures and other high-quality graphics were available. In a very few years E-COM volume may reach 10 billion mail pieces per annum if wide customer acceptance is achieved.

1.2 CURRENT USPS EFFORTS

The USPS is investigating several non-impact-printer options for introducing graphics into the E-COM service. One alternative is the use of a web-feed printer such as the HP 2680 or the Datagraphix 9820. Another choice is one of the smaller cut-sheet feed printers. The Delphax Model 2460 ion-deposition print engine is an example.

Both an HP 2680 and a Datagraphix 9820 have been purchased for USPS evaluation. The Datagraphix 9820 is installed at the USPS R&D Laboratories in Rockville, while an HP 2680 is being tested at the Detroit SPO. Both devices

have tractor feed. This allows compatibility with existing E-COM cutter-folder-enveloper equipment. Relative to the P300 Printronix printers currently in E-COM use, both new machines have higher resolution and print rates. The HP system prints on a 180 by 180 pels/inch matrix at 45 pages per minute in some formats, while the 9820 has a nonsymmetric 180 (horizontal) by 144 print matrix and prints at 160 pages per minute. However, both systems are bulky and expensive. The cost of the Datagraphix is about $300K; the HP system, about $150K.

The HP 2680 printer is designed to be used with an HP 3000 computer system. The package is called the HP 2685. With a software package called the Interactive Design System and an HP 2647/48 graphics terminal, 9874A digitizer, or 9111A graphics tablet, a user can create logos and other graphics. The graphics are organized on a character cell basis. Characters can be as large as 255 by 255 pels. Thus a logo could require several characters. Other system software builds an environmental file. This defines all graphics and is down loaded to the printer's processor, called the data control system. The environmental file is followed by a spool file containing ASCII character data and printing commands. Printing is the final step.

Another class of printers being investigated by the USPS consists of the cut-feed nonimpact printers. These run at 30 to 60 pages per minute and tend to be compact and less expensive than web-feed printers. They are attractive choices since at least two printers may be required at each E-COM site. It is anticipated that within a year about 30 vendors will be introducing a printer of this type. A paper, Program Task for Low-Cost-Non-Impact Printer Adoption Under Improved E-COM Equipment Program, has been written by T. Barnum, of the USPS. It proposes developing a general interface for adapting these low cost printers to USPS service and designing a web-feed transport to convert cut-sheet feed printers to web-feed input.

1.3 NOSC EFFORT

NOSC has been requested to study the implications of adding graphics data to E-COM messages. The study involves in part the effect of graphics on the printing process, storage, retrieval, formatting, compression, communication bandwidth, and the method of providing the digitization of customer-submitted graphics data. These subjects are covered in some detail in this appendix.

2 GRAPHICS REQUIREMENTS

This section discusses the addition of graphics capabilities to E-COM. Because of our limited familiarity with E-COM, some of our assumptions may not be valid for eventual implementation. Some of the ideas, however, should stimulate progress toward the incorporation of a graphics capability into E-COM.

2.1 FORMATS - CUSTOMER NEEDS

An initial NOSC goal was to provide potential customers considerable latitude in format choices for the position and sizes of logos and signatures on the document page.

Except for the sender's address field and the addressee's field, the entire page could be made a candidate area for graphics data. The available first page space on the document is shown in figure B1.

The present Printronix printers produce 60 circular dots per inch horizontally with the option to offset the subsequent row by one-half the normal increment, making the horizontal point density 120 dots per inch. In the vertical direction, the rows are spaced at 72 per inch. Text characters are confined to a 6 by 8 array, usually using a 5 by 7 format. For regular text messages, the 10 characters per inch provide the 80-column accommodation. Either 6 or 9 text lines per inch are allowed vertically. In the 9 lines/inch mode, the bottoms of lowercase "g" or "y" may become tangent to the top of a character such as a capital "O" in the next line below.

For rectangular forms, special characters are used to draw continuous horizontal and/or vertical lines, corners, and branches. The vertical character pitch is set at 9 lines per inch. The vertical 8-dot patterns at 9 lines per inch constitute continuous vertical lines. The use of a 6-dot horizontal character at a horizontal pitch of 10 characters per inch provides continuous horizontal lines.

For the printing of logos or signatures, horizontal scan densities of 60, 120, or 240 dots per inch and vertical scan densities of 72, 144, and 216 are common multiples of the current scan densities. Final selection of scan density depends on the performance of the chosen printing equipment and customer acceptance of the resulting graphics quality.

An option to allow the user to call up as many as three logo or signature areas per page could prove useful for a full range of capabilities, as shown in figure B2. With the current printer 120 by 72 format, the user area of a page may be partitioned into 960 horizontal increments of 0.00833 inch and 792 vertical increments of 0.01389 inch. Other spatial resolutions such as the Delphax printer's 240 by 240 pel capability are discussed in other sections of this report.

In figure B2, a header logo, an authenticated signature area, and a footer logo are accommodated. Logo location, height, and width may be selected in a number of ways. A standard 8.5 by 11 inch E-COM page may be divided into 80 horizontal groups of 12 pels (one character width) or 0.10 inch at 120 pels per inch (80 g × 12 p = 960 pels = 8.00 inches), and groups of vertical pels may be chosen to start at upper corners of character spaces. Thus, with this quantification, any desired starting address, to ± 0.05 inch in X and one character line in Y on the page, can be identified by using 6-bit addresses for X and Y positions. For our study, we have arbitrarily chosen this address to be the upper left-hand corner of a chosen graphics area.

Similarly, the height and width of the logo area can be partitioned in the same-sized 12-pel groups, with a restriction on logo height of perhaps 9

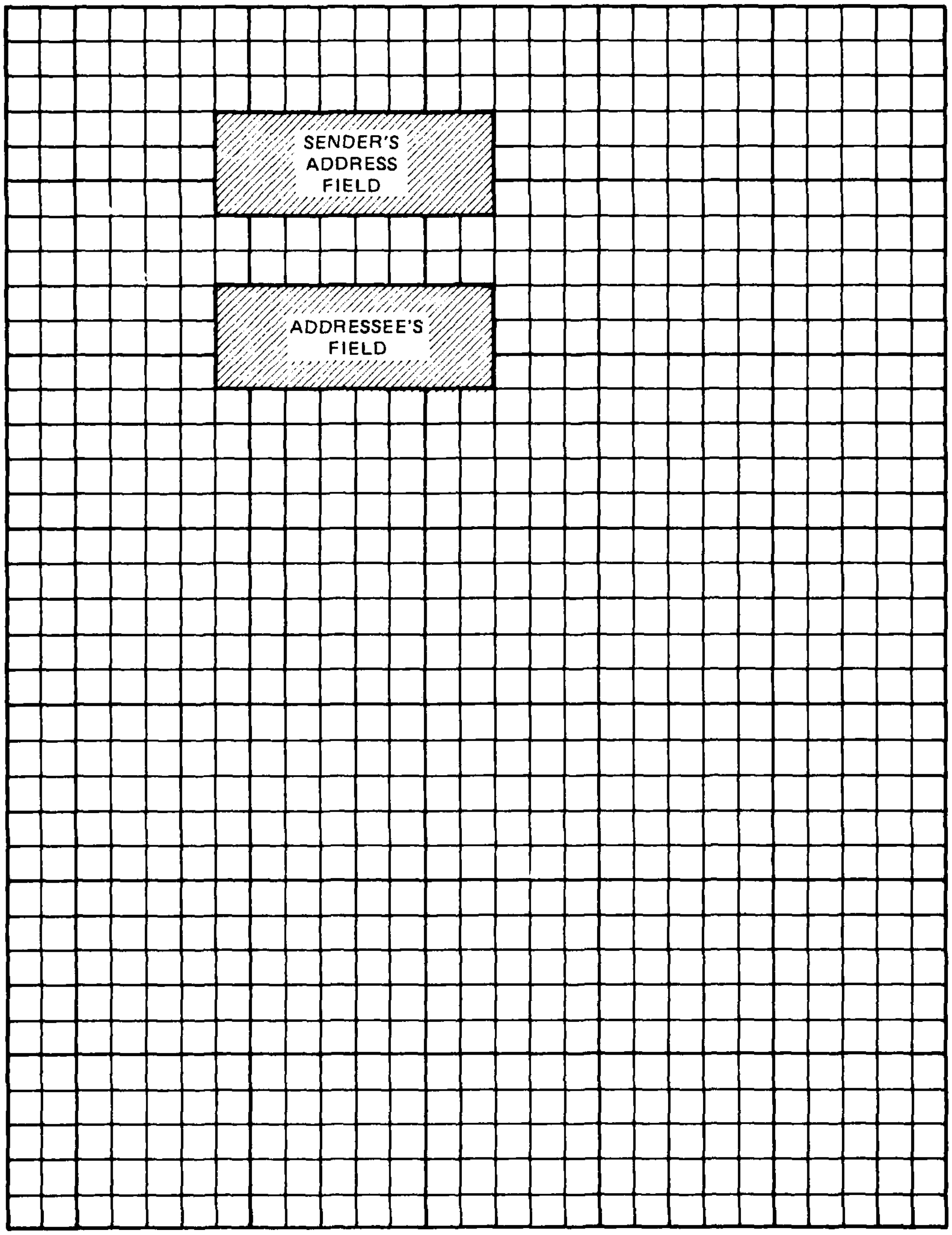


Figure B1. E-COM message address areas.

Satellite Lawnseed Corp.
Subsidiary of Ace Musket
271 Catalina Blvd.
San Diego, CA 92152
27-JUL-82 13:27 5476 0001
27-JUL-82 17:13 1058b SAN

SATELLITE
LAWNSEED
COMPANY

Mr. Frank C. Martin
Chalced. Inst. of Techn.
1227 Chalcedony St.
San Diego, Ca. 92109

Dear Mr. Martin:

This letter is written in the format for Electronic-Computer Originated Mail, E-COM. The format consists of a first page area starting 3-2/3 inches (9.31 cm) from the top of the page. The sender address starts on the third line, indented 10 additional spaces from the document text left margin. Three lines at 26 characters per line are available for the sender address field, plus two lines for USPS communications use. A five line space is left blank, followed by the addressee's data. Four lines of 26 characters per line are available for this data. The text portion of the first page of the letter is written at ten pitch (at 80 characters per line), either at 6 or 9 lines per inch. A 1/4 inch (0.635 cm) margin must be left at each side of the page. A 1/2 inch (1.27 cm) margin must be left at the bottom of the page.

For each additional page, a space of 9-1/3 inches high of 80 characters is available. The available space starts 1-1/6 inches from the top of the page. The same quarter-inch side margins and half-inch bottom margin apply. Messages of one or two pages are permitted. This document text required 2153 Wang word processor keystrokes to compose. In ASCII, the data herein requires 17,224 bits for transmission or storage. Horizontal and vertical ruling capabilities for the generation of rectangular boxes are available if submitted in the proper format.

With this test document we wish to demonstrate how logos and authenticated signature blocks can be added to this standard E-COM format with minimum impact on the equipment suite now in place at each E-COM serving Post Office (SPO). More versatile arrangements of the logo date can be accommodated, but would require retooling the envelope and changing the format of the header information.

John Hancock

John Hancock
V. P. Marketing
Satellite Lawnseed

OUR GRASS IS ALWAYS GREENER!

Figure B2. Sample E-COM document with two logos and signature.

characters (1.00 or 1.50 inches, depending on the mode setting of 6 or 9 lines per inch). Rough dimensional requirements for a maximum graphics capability can then be calculated as follows:

Header logo: 37 characters X by 6 lines Y at 10 by 12 pels per group = 26 640 bits (3.330 Kbytes)

Signature area: 22 characters X by 4 lines Y at 10 by 12 pels per group = 10 560 bits (1.320 Kbytes)

Footer logo: 80 characters X by 4 lines Y at 10 by 12 pels per group = 38 400 bits (4.800 Kbytes)

Total = 9.450 Kbytes/message (first page)

In the figure, it is assumed that the printer can operate only in the character mode <u>or</u> the plot (graphics) mode. Larger logos could be presented if the printer/plotter can accommodate simultaneous generation of characters and graphics. This could be accommodated if source data from the logo store text symbol generator can be logically "or"-ed into the print line buffer.

The slow speed and low resolution of Printronix mechanical printers appear to be limiting the future of these units to expanding E-COM systems, especially where quality high-resolution logos are required.

3 APPLICABLE E-COM PARAMETERS

3.1 USPS ESTIMATES

This study is based on parameters furnished by the USPS. The numbers given are forecast estimates based on the best information available at this time.

1. Figure B3 shows the estimated message volume growth over the next 5 years.

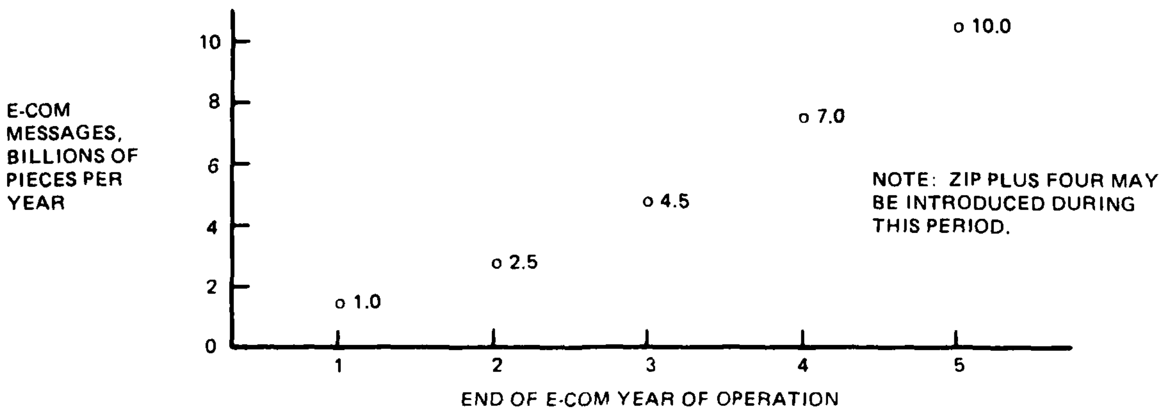


Figure B3. Expected growth of E-COM.

2. There will be 5000 E-COM customers at the end of the fifth year.

3. There will be 3000 E-COM customers using logos.

4. There will be 25 serving post offices (SPOs).

5. There may be up to 26 additional remote printing stations (RPSs).

6. Projected average message length is 1.25 pages.

7. Estimated average message content is 1400 characters/message.

8. Characters are American Standard Code for Information Interchange (ASCII) at 7 bits/character plus a parity bit. It is understood that in E-COM, the parity bit is not used.

9. About 45% of messages submitted by customers to a SPO require transmission to another SPO.

10. The ratio of peak to average traffic level will be 10:1.

11. Calculations for daily message volume from yearly estimates should be predicated on 300 days per year operation.

12. Overhead reporting to the USPS Management Operation Center (MOC) requires only 28 bytes/message.

3.2 NOSC ASSUMPTIONS

To these parameters, we have added further assumptions for estimating purposes.

1. There will be three sizes of SPOs: super SPOs (2), standard SPOs (21) and mini SPOs (2) (table B1).

2. Super SPOs' average message volume is twice that of a standard SPO and mini SPOs' average volume is half that of a standard SPO.

3. Graphics areas of 1 inch by 1 inch, 8-1/2 inches wide by 1 inch, and full-page (8-1/2 by 11 inches) will be used to test feasibility.

4. A communications overhead rate of 30% will be required for protocol, error detection and correction (EDAC), and encryption/decryption.

5. Available landline/microwave digital channel capacities are as follows:

   AT&T = 56 Kb/s

   AT&T T-1 line = 1.544 Mb/s

   AT&T T-1C line = 3.15 Mb/s

   AT&T T-2 line = 6.312 Mb/s

AT&T T-4M line = 274 Mb/s

6. Available satellite communication channel capacities accommodate port bandwidths of

56 Kb/s 1.544 Mb/s 3.150 Mb/s	Combinations of these up to a total of 48 Mb/s can be accommodated by one ground station dish.

7. Available magnetic tape decks and tape reels can accommodate

2400-foot, 1/2-inch reels
6250 bytes/inch tape density
125 inches/s read/write speed

SPO No.	SPO	E-COM Volume at Year End (millions of pieces)									
		1		2		3		4		5	
		Y	D	Y	D	Y	D	Y	D	Y	D
1	NYC, Lower Manhattan	77	0.256	192	0.641	346	1.154	538	1.795	769	2.564
2	Los Angeles, CA	77	0.256	192	0.641	346	1.154	538	1.795	769	2.564
3	Detroit, MI	38	0.128	96	0.320	173	0.577	269	0.897	385	1.282
4	Philadelphia, PA	38	0.128	96	0.320	173	0.577	269	0.897	385	1282
:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:
22	Milwaukee, WI	38	0.128	96	0.320	173	0.577	269	0.897	385	1.282
23	Minneapolis, MN	38	0.128	96	0.320	173	0.577	269	0.897	385	1.282
24	Denver, CO	19	0.064	48	0.160	87	0.288	138	0.449	192	0.641
25	Phoenix, AZ	19	0.064	48	0.160	87	0.288	135	0.449	192	0.641

Y = yearly D = daily

Note: This table does not include the 10:1 factor for peak load days.

Table B1. Expected 5-year growth of E-COM.

From these given USPS parameters and the NOSC assumptions, it is possible to generate an equation relating the required bandwidth to expected E-COM message traffic load, as follows:

$$T = (1 - R) \times \frac{D}{B} \times C \times (1 + K) \times A \quad ,$$

where

R = Percentage of mail per SPO retained and not transmitted to other SPOs (estimate R = 55%)

1 - R = Percentage of mail per SPO transmitted (1 - R = 45%)

D = Average daily SPO volume transmitted, pieces per day

C = Average number of characters (ASCII bytes) per message (estimated at 1400 characters/message)

B = Communication channel bandwidth, Hz

K = Overhead rate (estimated at 30%)

A = Number of bits per character

T = Transmission time per day in seconds

Thus

$$T = 0.45 \times \frac{D}{B} \times \frac{1.4 \times 10^3 \text{ char}}{\text{message}} \times (1.3) \times \frac{8 \text{ bits}}{\text{char}} = 6.552 \times 10^3 \times \frac{D}{B} \quad . \qquad (1)$$

4 GRAPHICS EQUIPMENT REQUIREMENTS

4.1 E-COM SITE IMPACT

The introduction of logos to E-COM appears to be a natural extension of the primary text transmission (PTX) mode described in section 3.3.4 of the E-COM User's Technical Guide*. This format now stores a common text skeleton for use in text insertion messages (TIM) or common text messages (COT). The PTX transmission contains text control blocks that define tabs, ruled forms, and margins. These blocks could also contain the call numbers for logo and signature data and provide the coordinates for placement on the parent document. The actual storage requirements for a very ambitious but low-density set of graphics data is 10 Kbytes. Depending on the dimensions and

*E-COM User's Technical Guide, USPS Handbook DM-501, November 1980.

speed of the storage media for the text/logo/signature control blocks, the text control block could contain either the graphics data locally or an address in mass storage where the graphics data are located. As messages are queued for printing, a time allowance for retrieval and staging of the graphics data for concurrent presentation to the printer/plotter is required. Figure B4 is a sketch showing this process. E-COM mail is held at the receiving SPO for merging and sorting into carrier sequences. The alternate PTX text/logo/signature formats must be fetched for each document type or stored in a local buffer for the day's use.

If higher density graphics of large dimensions are to be accommodated, then significantly greater SPO E-COM storage and software requirements will be necessary to provide the necessary retrieval and staging protocols.

As printing speeds increase (a possibility when the HP 2680A is integrated into E-COM), high-speed RAM may be required to support the printer/plotter. If merging and sorting of multiple E-COM customer inputs amounts to considerable volume, advanced software using linked list techniques and high-speed memory will be a real requirement.

4.2 GRAPHICS CONTROL BLOCK CONSIDERATIONS

The addition of graphics data to the E-COM message format will require some system modifications. First, the E-COM SPO resident software must be modified to accommodate and react to having a graphics control block. For the early testing stages, the software for the daily message-handling process not including graphics need only be programmed to ignore the added control block. The R&D equipment to test the concepts then can be reading the graphics input control block off line and triggering the test events as required.

As graphics capability goes to on-line production, the software will be required to react to the control block in a number of ways. Some are listed as follows:

Recognize the log-on code

Identify the number of logos on the first page

Authenticate bona fide user identity

Extract the starting pel and line coordinates for each graphic

Direct the graphics serial number to the graphics storage disk controller

Direct the graphics starting coordinate data to the printer format controller

Increment SPO management data base when the process is completed

An example of a candidate graphics control block format might be as follows:

$LOG (space) n, x_1, y_1, ser_1, x_2, y_2, ser_2, x_3, y_3, ser_3

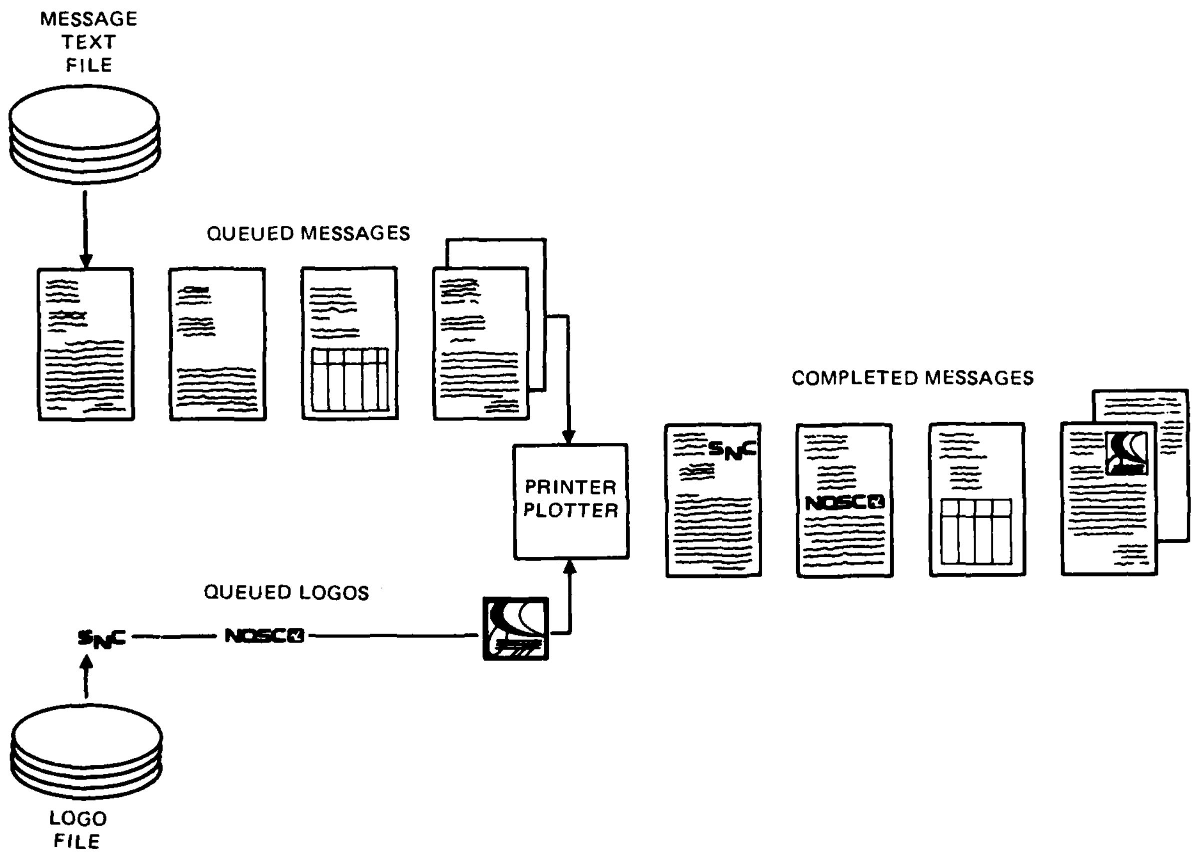


Figure B4. Staging of message and logo/signature data for printing/plotting.

where

$LOG (space) = the call for logo(s) or signature (5 bytes)

n = number of logos and signature for this document (up to 3 with our rules) (1 byte)

x_1, y_1 = the coordinates of the starting pel and starting line for the first graphic of the document first page (4 bytes each)

x_n, y_n = the coordinates of subsequent graphics (4 bytes each pair)

ser_1 = the authentication number of a specific legal logo or signature (5 bytes)

ser_n = the authentication number of subsequent graphics (5 bytes each)

An example might be:

$LOG (space) 3, 1460, 0691, 44871, 1215, 2312, 44872, 0096, 2471, 44873

The maximum number of characters in a graphics control block is as follows:

$$\underbrace{\underset{5}{\text{\$LOG (space)}}\quad \underset{1}{n}}_{6}\qquad \underbrace{\underset{1}{,}\ \underset{4}{x_1}\underset{1}{,}\ \underset{4}{y_1}\underset{1}{,}\ \underset{5}{ser_1}}_{16}\qquad \underbrace{-\ -\ -\ -\ -\ -\ -}_{16}\qquad \underbrace{\qquad\qquad}_{16}$$

Total: 54 characters (bytes)

This will increase the average E-COM message from 1400 characters to 1454 characters, a change of less than 3.9%. The remaining graphics dimensional data defining pel width and height in number of lines are contained on the graphics storage disk and need not be transmitted each time a graphic is called.

4.3 PRINTERS FOR GRAPHICS

4.3.1 Principal Current Candidates

At present, at least three companies are offering high-performance printers having capabilities satisfying at least the near-term USPS E-COM needs. These three candidate systems are described in the following paragraphs. Summary table B2 compares the performance of the important parameters.

Parameter	Delphax 2460	Datagraphix 9825	HP 2685	Printronix P-600
Printing technique	Ion printer	Laser printer	Laser printer	Solenoid hammer
Paper type	Plain, nonrag 8 1/2" by 11", cut sheet	Plain, edge-punched fan-fold	Plain, edge-punched fan-fold	Plain, edge-punched fan-fold
Plot density X	240 pels/inch	180 pels/inch	180 pels/inch	60 pels/inch half-pel option
Plot density Y	240 pels/inch	144 pels/inch	180 pels/inch	72 pels/inch
Input type	8 bit byte + parity (parallel)	?	?	8 bit parallel ASCII
Input levels	TTL	?	?	
Total bits per page	5 385 600	2 423 520	3 029 400	403 920
Input format	Plot mode only	ASCII or EBCDIC	ASCII or EBCDIC	
Total pages per s	1.0	2.64	0.7583	Print: 13.2 s/page Plot: 19.8 s/page
Bits per s	5 406 720	6 398 092.8	2 297 194	
Bytes per s (calculated avg)	675.84K	800K	287 149	
Bytes per s (Spec) 0.9 duty cyc	750K	800K	287 149	
Height	18" (46 cm)	59" (150 cm)	48" (122 cm)	16.5" (41.9 cm)
Depth	17" (42 cm)	37" (94 cm)	26.4 (67 cm)	24.25" (61.60 cm)
Width	18" (46 cm)	104" (264.1 cm)	64.5 (164 cm)	30" (76.2 cm)
Weight		2500 lb (1134 kg)	890 lb (404 kg)	185 lb (84.1 kg)
Cost	\$60K (\$12K basic engine)	\$312K	\$150K	\$8K

Table B2. Some candidate E-COM printers.

Delphax Systems Model 2460 Image Output Module

Good features

IDAX ion deposition printing (Dennison patent)

Uses plain paper, 16 to 20 pound cut sheet

240 by 240 pels/inch

60 pages/minute with 8-1/2 by 11 inch paper

Feeds line at a time in "portrait" mode

Accepts conventional raster scan input: 8-bit bytes plus parity bit, parallel TTL

Line rate 2640 lines/second

Four function lines for mode control and sync

Sustained data rate of 750 Kbytes/second (615 Kbytes/second required for 8-1/2 by 11 paper)

Very low comparative cost

Small floor space (footprint)

Possible disadvantages

The ion generator lifetime may be limited to 200 hours (720 000 pages)

The high-pressure print roller adds a gloss to the bond paper and the compressed toner

The equipment is not presently available with sprocket feed for edge-punched fanfold paper

Datagraphix model 9825 printing subsystem

Good features

Laser printing on photoconductive drum

180 by 180 pels/inch

Paper speed: constant at 29-1/16 inches/second

Document (12 inch) speed: 2.42 pages/second

Uses plain paper, 18 to 27 pound edge-punched, web fed

Laser speed 5231 lines/second

Print rate is 7.344 Mbits/second, 918 Kbytes/second

Software for operating in the plot (graphics) mode is becoming available

Possible disadvantages

At present, hard-copy forms are overlayed by optical projection

The system is expensive

The system is physically very large

17 to 25 kVA power required

Hewlett-Packard HP 2685 laser printing system

Good Features

Laser printing on photoconductive drum

Prints 45 pages/minute in the landscape mode

180 by 180 pels/inch resolution

Extensive support software is available

Possible disadvantages

Prints only 22.5 pages/minute in the portrait mode

Would require modification of the cutter/folder/enveloper to operate at 45 pages/minute

Support software for graphics applications appears cumbersome

Requires HP 3000 computer as a host

4.3.2 Resolutions and Speeds

The present character font generated by the Printronix P300 line matrix printer for E-COM is produced by a 5 horizontal by 7 vertical array of pels confined to a 6H by 8V pel area at a pel resolution of 60 pels/inch horizontally (with half-pel displacement options) by 72 pels/inch vertically.

Comparison of the principal candidate printer formats in pels/inch are as follows:

Axis	Delphax	Datagraphix	HP 2680	Printronix
X	240	180	180	60/120
Y	240	144	180	72

An inspection of the data shows that the lowest common multiple of these values is 720. If graphics data were scanned at 720 pels/inch, then by combining sets of columns and rows all of the above formats could be accommodated.

The number of pel columns and rows scanned at 720 pels/inch to be combined for printing at each of the equipments' present resolutions are as follows:

Axis	Delphax	Datagraphix	HP 2680	Printronix
X, columns	3	4	4	12/6
Y, rows	3	6	4	10

A problem with scanning at this resolution for large graphics formats is the digital scanner aperture required for full-page width acquisition. The scanning equipment must accommodate 720 pels/inch by 8.5 inches = 6120 pels. An alternative solution is to scan orthogonally during the acquisition and then substitute $Y = X_{max} - X$ and $X = Y$ when combining. Another alternative is to scan portions of the logo in smaller subsets and to "tile" these as the page-width logo is formatted for the particular printer.

4.3.3 Character Generation

Standard business typed text is usually 10- or 12-pitch type at 6 lines per inch for single-spaced copy. Some modern word processors provide 1-1/2 spacing at 4 lines per inch and double spacing at three lines per inch. E-COM presently provides 10-pitch type with options of 6 or 9 lines per inch.

The resolution of 240 by 240 pels conveniently accommodates all the above selections except 9 lines per inch, since 240 is not evenly divisible by 9. By using 27 pel spaces vertically per character row, 8.889 (-1.2% error) lines per inch can be accommodated. By using 26 pel spaces vertically per character row, 9.23 (+2.6% error) rows per inch can be accommodated.

The font for 10-pitch type requires a library storage area of 24 pels horizontally by 27 pels vertically if we wish to keep the forms symbols contiguous at approximately 9 lines/inch. Some 10-pitch fonts require more than 27 vertical pels. For example, the Xerox print wheel for Spokesman 10 font has uppercase characters 0.165" (40 pels) high. Figure B5 shows a few uppercase characters printed at a fixed 10 characters per inch. By adding one additional row of storage per character in the font library, information may be stored to indicate width requirements for proportional-spaced typing. The second line of printing in the figure shows the results of utilizing the stored width control information, shown by the X boxes at the top of the figure to produce proportional-spaced printing.

For our investigation, we have selected an arbitrary rule that the upper left-hand used pel (to accommodate proportional spacing) is the reference coordinate for that character position. As long as the same reference system is used for the forms symbols, character and form lines should be spatially compatible.

The options of 10- and 12-pitch type appear to be reasonable hardware/software options for the microprocessor-based formatter/controller. The option for proportional-spaced typing consumes time in the formatting process which may exceed the 1 Mbyte output rate required for printing. We have made a quick pass at a line buffer organization for a portion of the microprocessor RAM memory. It might be organized as shown in figure B6. At 12 pitch, the maximum number of characters per line (with 1/2-inch margins) is 90. At 10 pitch, the number of characters per line is 75. By using a 7-bit address, a 128-column line character buffer can be generated. If proportional-spaced type is desired, more than 90 characters must be accommodated.

The table indicates the 8-bit byte stack for the ASCII text string. This must be accessed at very high speed during every raster plot line for that particular row of characters. The number of lines of access depends on the height of the font or, if the forms character set is called, the entire height of the field, which is 27 raster lines at approximately 9 lines per inch. The ASCII character byte plus the character plot line number must be sent to the proper font library to fetch the consecutive byte pel patterns for that character.

Figure B6 also shows a column that could be used for control of proportional-pitch typing. The 4-bit word could indicate how any pel positions can be deleted on each side of a narrow character such as the letter "I." The manipulation of this information for real-time formatting of character plot lines quickly becomes highly complicated and time-consuming in the processor and probably should be dropped from the initial upgrade goals.

The next column in the table may be used for setting and remembering tab column locations for a document page. A column is provided for a return (end-of-line) designator. Another column is provided for underline requests. With this indicator, high-speed generation of underlined text can be composed in one pass without doubling the font library size. The last column is provided for a word parity bit for the other 15 data bits in the double-byte character line buffer.

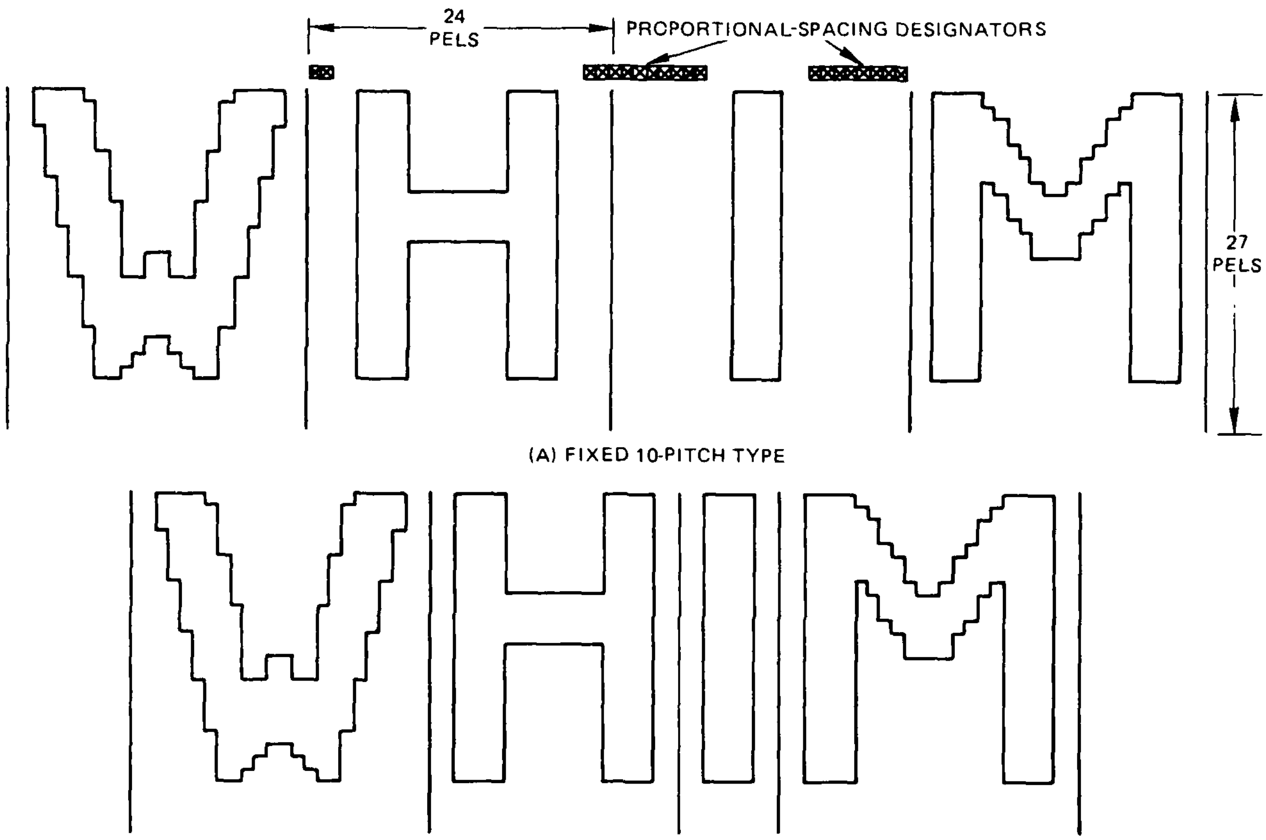


Figure B5. Ten-pitch font library storage requirements.

Character to be Printed	Character Column Number	Selected ASCII Byte	Proportional-Spacing Index	Tab Set Bit	Return Bit	Under-line Bit	Word Parity Bit
N	1	10101010	0011	0	0	1	1
o	2		0010	0	0	1	0
w	3		0001	0	0	1	0
	4		0010	0	:	0	1
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
a	86		0000	0	0	0	0
r	87		0011	0	0	0	1
t	88		0101	0	0	0	0
y	89		0100	0	0	0	1
:	90		1111	0	1	0	0
:	:						
:	:						
:	127						
:	128						

Figure B6. A version of a text line buffer.

The forms library should include the font characters such as are shown in figure B7. These 39 characters plus a host of others could be used to compose some reasonably sophisticated and attractive forms. Since at least 39 characters are needed, it is impractical to replace an equivalent number of unnecessary commands or characters from the standard ASCII set. Therefore, a second library dedicated to the graphic forms generation task is recommended. If a second library is used, graphic fonts for the modular assembly of large areas in logos could also be stored as graphics character building blocks if the graphics forms library is expanded to the full 255 characters. Full (and half, etc) character areas representing 24 by 27 pel block areas (648 pels) can be stored and retrieved by using only 8 character address bits plus one control bit denoting graphics forms library rather than the standard ASCII library. Using solid block full-character and perhaps several half-character blocks as well as perhaps even a few half-tone shades might measurably compress the storage requirements and composure time of pages containing logos.

Maximum data transfer rates into the Delphax are determined by the page rate. The Delphax representative has stated that Delphax may soon offer a model with tractor drive for edge-punched, fanfold paper printing in the portrait mode at 90 pages/minute. At 2048 pels/line and 240 plot rows/inch, the maximum data transfer rate for 11-inch paper can be calculated. The line rate in this instance is 3960 lines/s and the pel rate is 8.11008 Mbits/s or 1.01376 Mbytes/s. For 12-inch paper, subsequently cut to 11 inches, the average byte rate into the Delphax 16-line plot buffer would be 1.1059 Mbytes/second.

At 1.5 pages/second, the composition time for each complete document page must be 666.7 milliseconds or less. If, in some hypothetical case, the entire page were composed of a customer logo, the input data rate would be the same as the Delphax rate, either 1.01376 Mbytes/s or 1.10592 Mbytes/s. If the page were composed of 12-pitch single-spaced (6 rows/inch) character information, the ASCII byte rate would drop to 5940 (90 characters by 66 rows) character bytes/page or 8910 bytes/second. At 10 pitch, this number drops even lower, to 5280 bytes/s.

4.3.4 Delphax Formatter/Controller

The use of the Delphax 2460 image output module as the primary advanced E-COM printer requires some special considerations. It not only has higher pel spatial resolution (240 by 240 pels) than the other two major present candidates (180 by 180 pels or less), but it is intentionally designed to be a "dumb" printer--dumb in the sense that it has no formatter/controller. It prints raster lines of data after receiving 8-bit bytes plus a parity bit for line printing in the plot mode.

Any formation of characters must be composed into plot lines before entry of the data into the 2460. The responsibility for generating data for entry into the 2460 is left to an input equipment designated as a formatter/controller (F/C). The width of the ion printer matrix is 2048 pels, which, at 240 pels/inch, is 8.533 inches. The F/C is responsible for ensuring that no pels are written beyond the edges of the document.

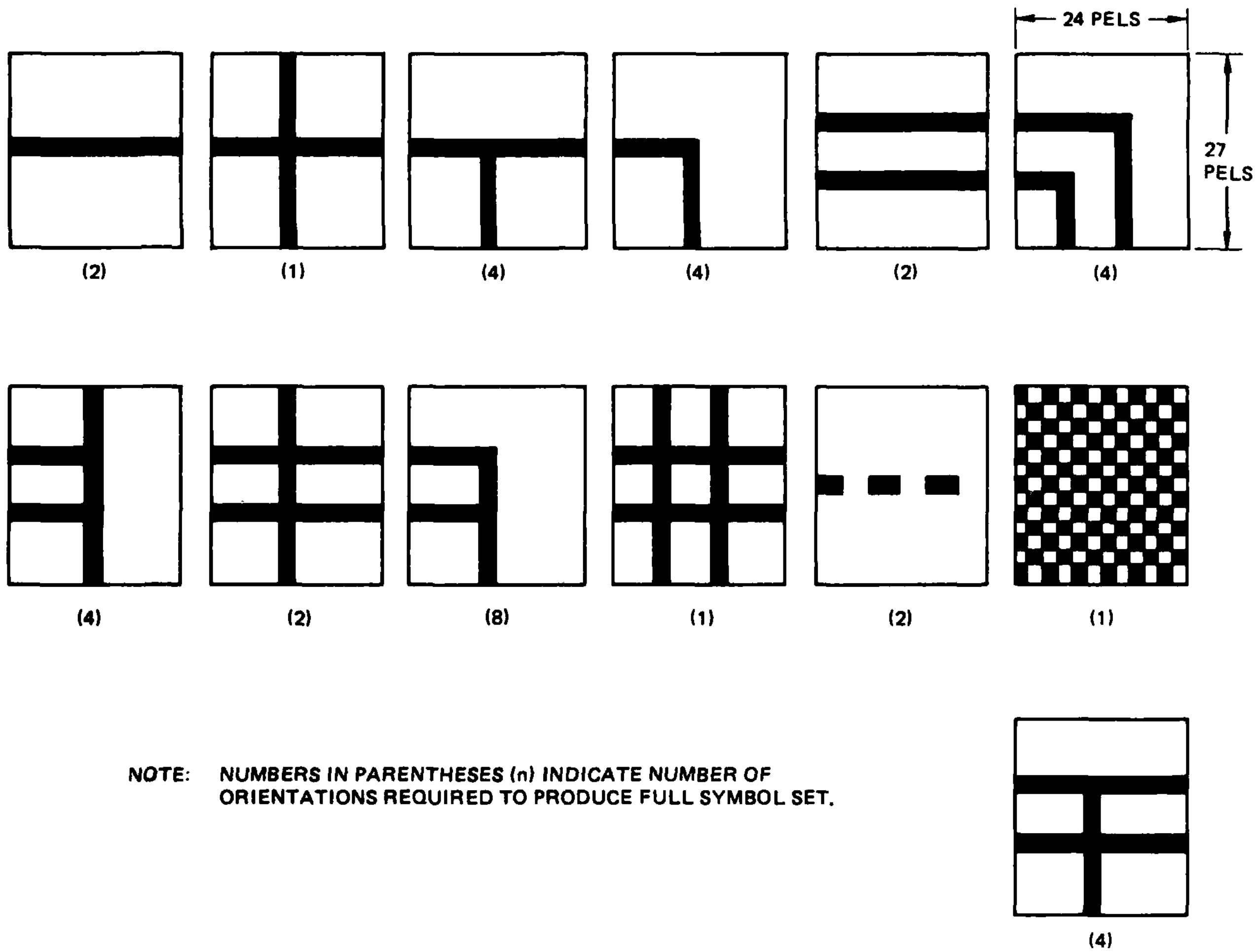


Figure B7. A 39-character forms library.

A new standard of high-performance logic modules based on the Motorola MC68000 microprocessor unit is emerging in both the US and Europe. The packaging concept is based on a worldwide standard, the Eurocard.

The MC68000 is a very high performance 16/32-bit microprocessor designed for optimal support of the latest high-level language and will address up to 160 megabytes of memory.

The packaging concept and operating system accommodate modular processing of 16/32-bit words via the VME bus.

Motorola offers a high-level operating system called VERSAdos, which accommodates the operation of the MC68000 MPU and associated memories on the VME bus.

Other companies such as Mizar are also providing high-performance modules that meet the standard bus structure and mechanical packaging accommodations of the VME enclosure.

In the investigation of USPS E-COM upgrade, it is becoming practical to assess the applicability of high-performance microprocessor subsystems made from readily available, reasonably low-cost modules that may significantly upgrade the performance, available user options, and throughput at a significantly lower cost than that of larger scale general-purpose data processing equipment.

For this design the following very ambitious goals were established:

Capability to write characters over entire page

Capability to superimpose graphics data with text over entire page

Multiple font selection

Choice of 10-pitch, 12-pitch, and proportional-spaced typing

Choice of 4, 6, 9, or 12 character lines/inch

Expanded forms library

High data rate of 1 to 1-1/2 pages/second

Reasonable subsystem cost, allowing economical replication for expansion

Where possible, standard off-the-shelf packaging, electronic modules, and software operating systems

Low power dissipation

Small size

Minimum impact on present E-COM protocols and SPO hardware

With regard to the last item, an effort was made to design any new equipment interface to be compatible with the existing SPO suite. This consideration was not allowed to compromise the design if the system performance would be impacted. The present DEC PDP-11 processors and the UNIBUS provide the capability to expand and upgrade the hardware and software capabilities of a SPO with very little impact. This interface is discussed in a later section of this document.

A block diagram of a system design based on the VME module system and configured to achieve all these goals is shown in figure B8. The most important module in the equipment is the monoboard microcomputer, Motorola model MVME110-2. It is a double-width Eurocard having length by width dimensions of 6.3 by 9.2 inches. It requires a 16 megahertz clock on a separate board for the VME bus. All boards in the VME series are fitted with pin-and-socket bus connectors to give an extra margin of reliability in sensitive environments. The module contains eight 28-pin sockets, allowing the addition of either 128 Kbytes of ROM or 64 Kbytes of RAM. The module plugs into an enclosure that contains the VME and I/O buses. The microcomputer operates on a 56-instruction set and contains seven interrupt levels with full arbiter, requester, and interrupt support. It has an LED status display and reset and abort control buttons. It also contains a port for RS-232C serial I/O communication. In single quantities, the module is sold for approximately $1700.

Another Motorola module, the MVME201, is a 256-Kbyte dynamic RAM module. This module is organized in four blocks of 64 Kbytes. The words are 16 bits wide. The module has a double-Eurocard form factor and has a single connector that plugs directly into the VME bus. The module contains a parity generation and check feature at the byte level. The read/write cycle time is 500 nanoseconds. The module contains on-board dynamic RAM refresh circuitry.

Another module that may be required for interface with the Winchester disk is the dual-channel 16-bit parallel port module, Motorola Model MVE410. This module has a single-Eurocard form factor. It connects to the standard VME I/O bus in the base plane and provides two separate 16-bit software-controlled outputs on a front panel connector. Each of the outputs contains two control lines. This module may be required in the architecture to connect 68000 microprocessor 3 to the disk controller and to the VME I/O channel.

The Winchester disk controller I/O module, Motorola model M68RWIN1-2, provides control for up to two daisy-chained, 8-inch Winchester disk drives and up to two daisy-chained double-density single- or double-sided floppy disk drives. The module is 12.4 inches by 8.25 inches and mounts in the Motorola M68MRSE1-2 RETMA rack-mountable enclosures for 8-inch drives.

Another module that may contribute to the system is the MVE static RAM/ROM module, which has a double-Eurocard format and is VME bus compatible. It may contain up 128 kilobytes of either static RAM or ROM memory. This module may be used to store the standard character sets in different fonts for the typing and forms generation for the system. The module contains 16 sockets for 28-pin and 24-pin memory devices. Access time is jumper selectable in increments of 60 nanoseconds, with a minimum of 120 nanoseconds

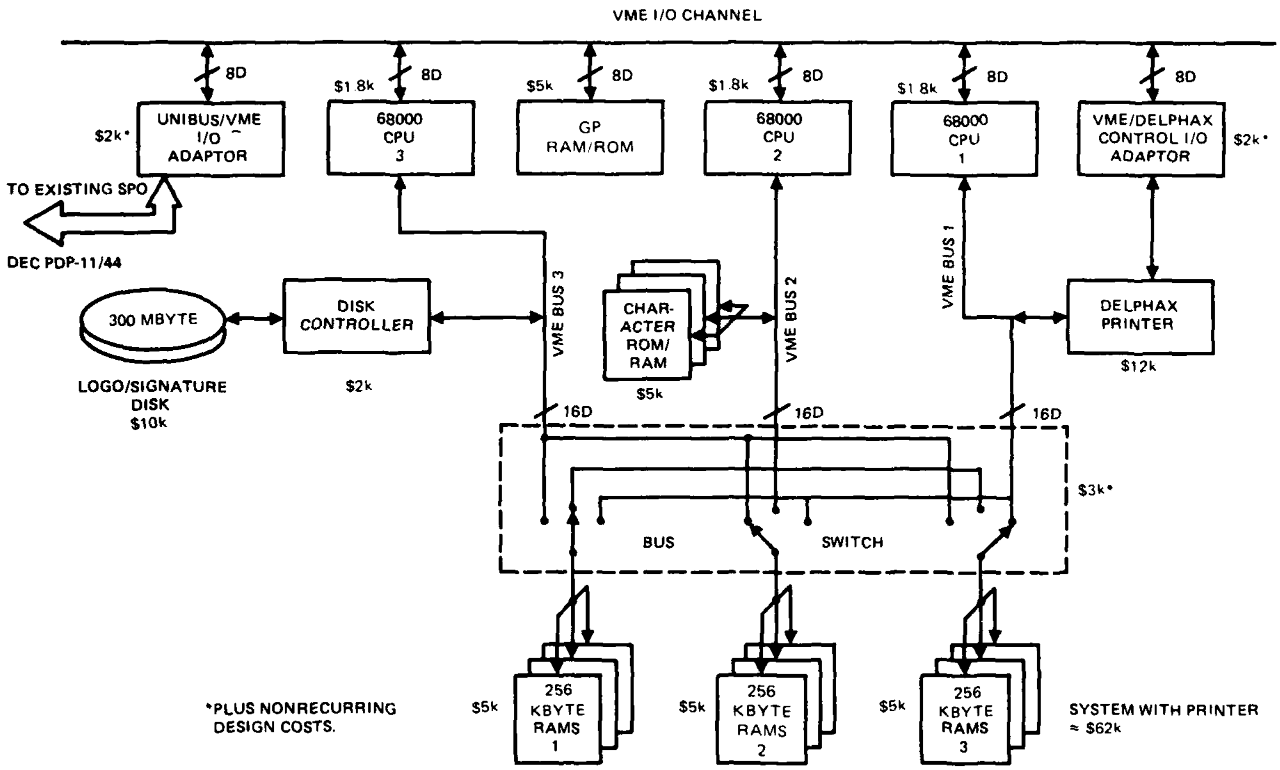


Figure B8. Candidate architecture for a formatter/controller.

and a maximum of 600 nanoseconds. The memory module is organized in four blocks. The base address of each block can be selected by jumpers in an 11-bit field.

In the logic block diagram of the proposed printer formatter/controller equipment, there remain three modules that are nonstandard. One of these is the UNIBUS-to-VME I/O adapter, which will connect the equipment to the existing USPS PDP-11/44 processor.

A second control I/O adapter is required, to interface the VME to the Delphax printer. This module accepts data from the Delphax printer control lines indicating paper demand, jams, requirements for filling the line buffer, etc.

A third module, which does not appear to be off-the-shelf, is badly needed for a configuration having the very high throughput required for this application. This is the bus switch module, which performs the function of making the document page memories triple-ported. The requirement for this feature is explained in subsequent paragraphs.

At the bottom of figure B8, three 256-Kbyte RAMs are shown for each of three one-page document memories. Each page memory requires approximately 675 kilobytes to describe every pel on an 8-1/2- by 11-inch page area having a print spatial density of 240 by 240 pels/inch.

The function of the formatter/controller is to format the incoming E-COM control and text data blocks into raster plot format for the Delphax printer. Each plot line (at 240 pels/inch) requires 2048 pels, and there are 2640 lines/page. One 68000 processor (CPU 2) is dedicated to accept the ASCII text and form data and to convert the lines of text and forms into plot lines for printing. This is accomplished in much the same manner as is done in the present PDP-11/44 and Printronix printer combination in the SPOs.

In this formatter/controller example, the plot data are accumulated in an assigned page memory RAM. The bus switch in the figure shows that RAM 1 is accepting formatted plot data from the text/form generation process. This formatting takes place two page print cycles ahead of the print buffer (RAM 3) loading of the Delphax.

While this process is under way for a page, a second memory (RAM 2) having already been filled with character information is being modified to include the graphics overlay data. In the control blocks of an E-COM message, a new entry must be added to authorize, identify, and provide location coordinates for graphics data. Data received by the formatter/controller are sent to CPU 3 for interpretation. In this processor, the identification of the logo or signature is read and the location and dimensions of the graphic data on the disk are sent to the disk controller. The data prestored on the disk are extracted and sent to the CPU for processing. Graphics data on the disk are stored in compressed form. It is expected that these data can be compressed by a ratio of about 8:1.

The function of the processor is to determine the starting line number and pel number on the line for the entry. Depending on the logo or signature area involved, the complete formation of the plot area sent to memory may take

several iterations because of capacity limitations. Text data have been added to the memory in which the logo is to be stored during the previous page cycle. For this reason, the graphics data must be logically "or"-ed with the text/form data. This means that the data from the text page must be returned from the memory to the processor, modified, and reentered into the same memory for buffering to the printer on the subsequent page cycle. A typical reason for "or"-ing the data is for a signature that extends (writes) over the typed name and title of the document author.

At the same time that these two processes are going on, for example with memories 1 and 2, memory 3 is rapidly providing data to the Delphax printer. In the worst case, the data rate into and out of these memories is about one megabyte per second.

In concept, this equipment would accept a page of data from the SPO PDP-11/44 in almost identical form to that in which it is now available. As mentioned above, the only additional format change to the PDP-11 character data stream is the addition of logo identification and location parameters required to fetch and position the logo or signature on the document pages. It is conceived that a page of data at a time would enter through the UNIBUS/VME I/0 adapter from the SPO 11/44 and be placed in memory of CPU 1. These data may be received in a single burst transmission or could be received in packets throughout the period of one page. Since the Delphax printer now operates at one page per second but may soon operate at 1-1/2 pages per second, the equipment must accommodate pages at a rate of about 1 per 667 milliseconds for each operation.

As CPU 1 receives data from the SPO processor, it parses the data into those applicable to the logo and those applicable to character or form generation. The character and form generation data are sent to CPU 2 in ASCII form. The graphics data are sent to CPU 3 in ASCII bytes in the form of authentication, logo identification, and the location of the logo on the document. Information regarding the number of pages in the document is transmitted to CPU 2, present thinking being that the document may contain up to five pages. This information is merged with the character and form information to flag the buckle folder following the Delphax printer concerning how many pages should be accumulated before a document is sheared and folded for insertion in an envelope.

This architecture is unusual: it requires three partitioned VME buses for the reason that each one contains data traveling at an information rate that nearly saturates the capability of this bus standard. For control, we have used the I/0 ports of all the processors to make it possible to pass information at up to 2 megabytes per second, 8 bits wide, from module to module. The bulk of the actual printed pixel information is carried on the VME buses rather than the VME I/0 channel.

It is envisioned that the graphics data stored on the disk can be compressed by a factor of approximately eight to one. Therefore, it is the responsibility of CPU 3, when given a particular logo identification number, to transfer the information from the disk into the CPU and decompress or expand the data back into full raster form for deposit in the applicable page random access memory in addition to the character data already present. As previously mentioned, this is done by "or"-ing" the data with the character and form information already residing in the partly processed page memory.

Specific pricing information for all these modules has not yet been obtained. The 68000 CPU microprocessor unit cost is approximately $1700. The 256 Kbyte RAM modules also cost approximately $1600--$1700 each. The Delphax printer cost as determined by NOSC team members visiting the Delphax booth at WESCON seems to be settling out at about $12 000. From these price estimates, it is possible to formulate a rough order-of-magnitude cost for equipment that would provide an operating speed of 1.5 pages per second and having most of the features listed at the beginning of this discussion on printers. The rough estimated recurring equipment cost is $62 000, including the printer.

It can be seen that the equipment entity, including the printer, is itself a modular replicable subsystem. Several of these subsystems could be put onto the DEC UNIBUS to expand the printing rate and provide redundancy to the SPO for peak loads, scheduled maintenance, or equipment failure.

4.4 GRAPHICS DIGITIZATION

The HP 2680A/2685 laser printer produces output at a fixed density of 180 by 180 pels per inch. The Printronix P300 currently in use at the E-COM sites prints at either 60 or 120 pels/inch in the horizontal direction and 72 pels/inch in the vertical direction. A third printer, the Delphax ion deposition unit, operates at a fixed density of 240 by 240 pels/inch. This variability in print density gives rise to difficulties when the attempt is made to digitize graphics to accommodate all three (and possibly other) print densities.

Since the HP 2680 and the Printronix P300 are the only two printers in the field, scanning of images on the USPS/NOSC Image Capture and Analysis System (ICAS) was set up for about 360 by 360 pels/inch. This followed the strategy discussed in section 4.5.2 regarding scanning at a super-resolution to allow future simple digital pel operations to provide coarser resolution subsets from the master graphics file. The resolution of 360 pels/inch was chosen to allow subsets at 180, 120, 72, and 60 pels/inch to be formed simply.

By means of this process, the logo SIGNETICS was scanned on ICAS at a grey scale resolution of 6 bits/pel (64 grey shades). A Xerox print of the logo is shown in figure B9. Scanning was done on the Scanner III optical bench by means of the Fairchild Model 143 charge coupled device (CCD). This image was then trimmed ("cropped") to 696 pels wide by 188 pels high, with the ICAS Tektronix 4054 terminal used as the operator's work station. To demonstrate the basic quality of the scanning operation only, no image restoration operations were added by the operator during this exercise.

Using the ICAS program for minification, the image was reduced in size by a factor of two in both dimensions. This was accomplished by summing the brightness values of 2 by 2 arrays of pels and normalizing by dividing by 4. The results are stored in the minified array format in another location of image memory. When this file is presented to the ICAS display, it produces a grey scale image 348 pels wide by 94 pels high. Half the resolution in each axis is lost by the minifying process. This process is represented by the "minify 2:1" path in the upper left corner of figure B9. The results of the minification can be observed in the photo, figure B10.

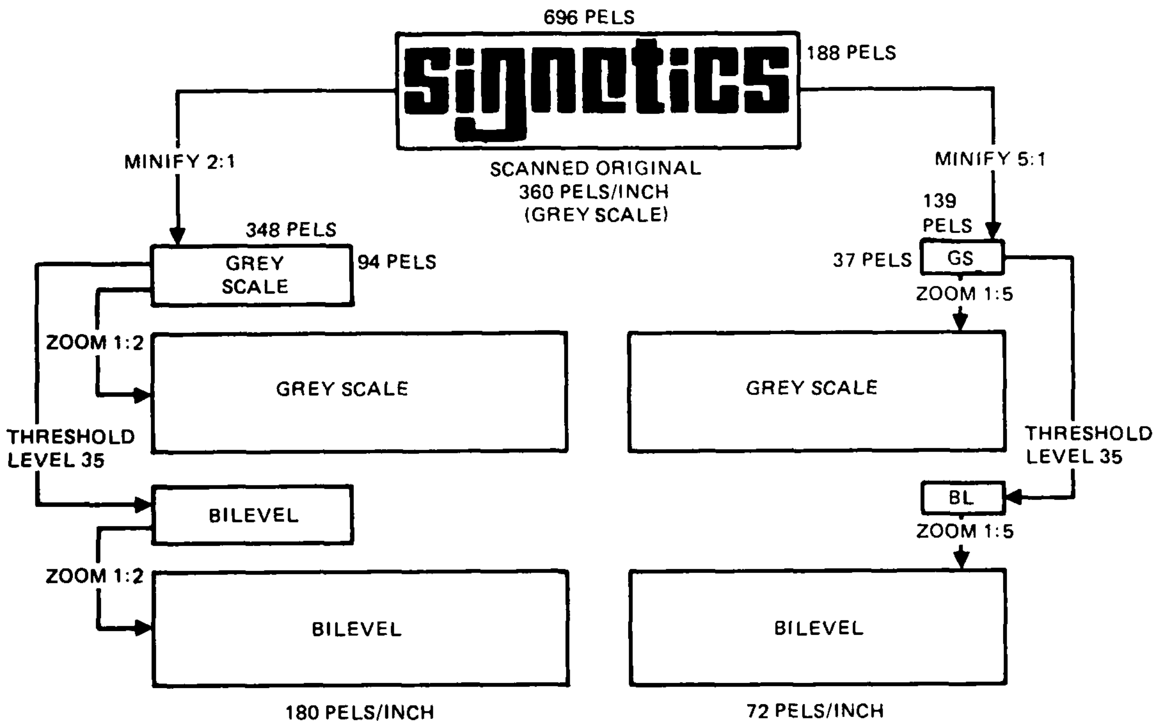


Figure B9. Generation of variable scan density logos. Logotype used by permission, Signetics Corp.

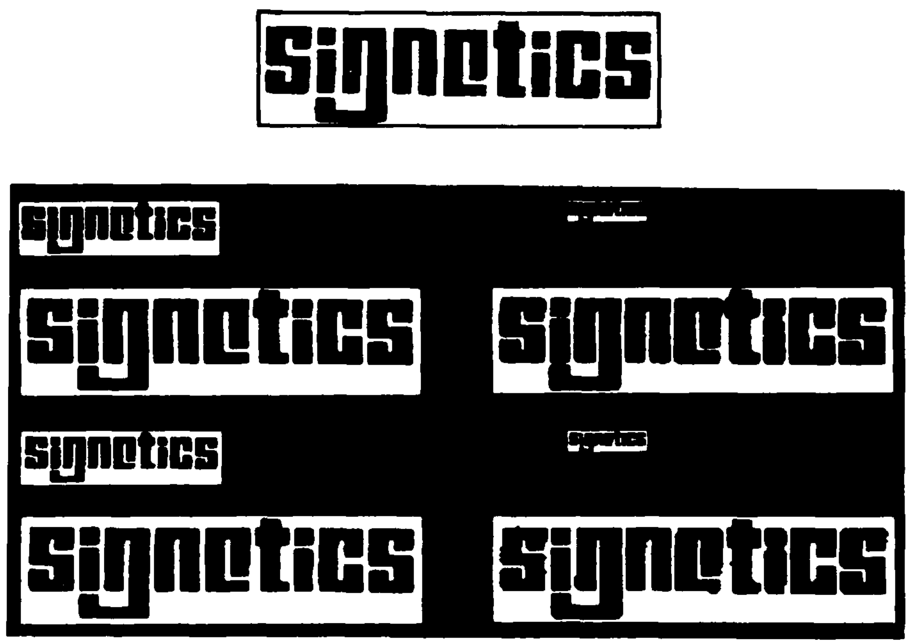


Figure B10. Photo of generation stages. Logotype used by permission, Signetics Corp.

The ICAS minification program was also used to minify by a factor of five in both dimensions. In this case a 5 by 5 array of 25 pels is summed and normalized by dividing by 25. The resulting pels, as before, are stored in a new location in image memory. The resulting array is 139 pels wide by 38 pels high. Since the original 696- by 188-pel super file was not evenly divisible by 5, rows and columns of background level imagery were dropped to round to the 5 by 5 arrays. Figure B9 indicates the 5:1 minification process in the upper right. Figure B10 shows the minified image. This image now has a resolution of 72 pels/inch and a subset of the 64 possible grey shades. Grey shades for the original super-resolution (360 by 360) image, the 180 by 180 image, and the 72 by 72 images are shown in figures B11, B12 and B13, respectively.

Our present minification and zoom programs for the ICAS do not accommodate anamorphic operations such as 3:1 X by 5:1 Y. If in the future digital tapes of logos prepared at 120 by 72 or 60 by 72 pels are desired by the USPS for experimental purposes, the current software can be modified in less than one work-day to accomplish the added capability.

At this point in the processing we how have three image files of the same logo, all having grey scale pel values. In the next pair of steps in figure B9, the minified files are passed through a threshold function. In thresholding, every pel whose brightness level is at or above the threshold value is considered white and is assigned the maximum brightness value, level 63. All pels less than the threshold value are assigned brightness level zero.

On the ICAS, thresholding is an interactive process where the operator can observe the effects of thresholding at different brightness levels. On an E-COM customer graphics digitization work station this feature is very desirable if not mandatory. On this particular logo, at the lens stop chosen, a threshold of level 35 was found to be optimum for both the 2:1 and 5:1 minified files. The results of thresholding are shown in figure B10.

The last step for operator confirmation of good logo data includes the zoom of the image into a data file where it can be presented on the display at some reasonable magnification, for quality inspection. At this time the operator may choose to perform image restoration techniques such as adding dropped pels or smoothing horizontal and vertical (or diagonal) edges as desired.

The two minified files can now be transferred to compatible printers, where samples can be made available for the operator and the customer. The USPS may wish to include in the graphics acceptance procedures that the customer be given a sample of the logo that has been digitized and printed on the same specific brand or make of equipment (or more than one, if this is the case in the field) that will be used in the actual SPO message traffic printing operation.

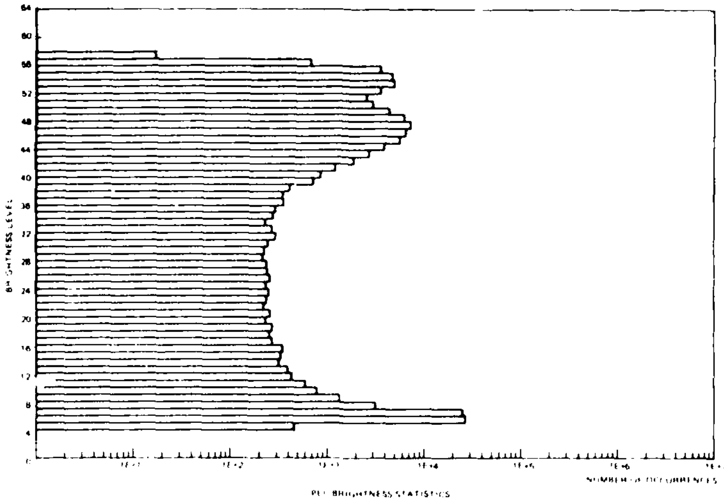


Figure B11. SIGNETICS logo, 360 by 360 pel/inch resolution.

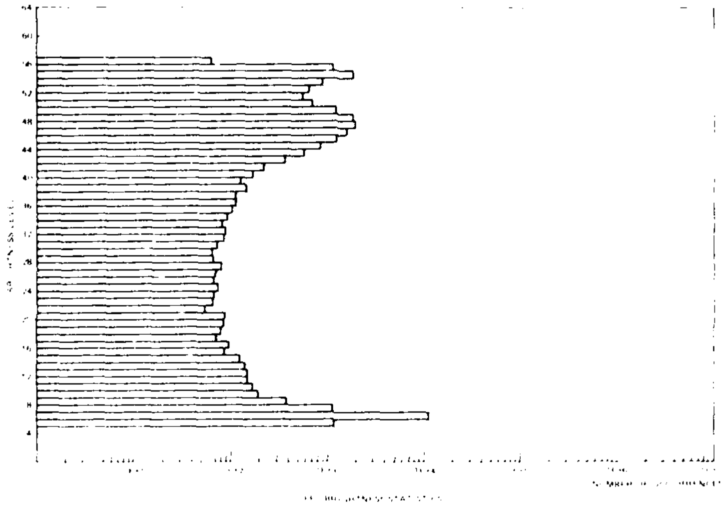


Figure B12. SIGNETICS logo, 180 by 180 pel/inch resolution.

Figure B13. SIGNETICS logo, 72 by 72 pel/inch resolution.

4.5 GRAPHICS MEMORY STORAGE AND RETRIEVAL CONSIDERATIONS

Assumptions:

1. Total number of E-COM customers at end of 5th year is 5000, of which 3000 require graphics

2. Graphics are represented with resolution of 240 pels per inch, both horizontally and vertically

3. Correspondence containing graphics is printed at 1.5 pages per second

There are then (240 by 240)/8 or 7.2 Kbytes of data per square inch of graphics space. An examination of some 40 different logos contained on business correspondence reveals that many of these logos reside near the top of the page and can be contained in a 1- by 3-inch rectangle. These logos would then require 7.2 × 3 Kbytes or 21.6 Kbytes of data at a resolution of 240 pels per inch. If 3000 logos of this size are in storage at each E-COM site, then 21.6 × 3000 Kbytes or 64.8 Mbytes of memory are required. This is a reasonable storage requirement that can be met by most 14-inch disk drives, some 8-inch, and even a few emerging 5-1/4-inch systems.

Memory storage requirements can be calculated for the three logo sizes hypothesized in our test case.

Given:

Minilogo = 256 by 256 pels (1.067 by 1.067 inches)

Standard logo = 2040 by 256 pels (8.533 by 1.067 inches)

Macrologo = 2040 by 2640 pels (8.5 by 11.0 inches, full page)

Capacity at each SPO site for 3000 graphics of each of the three sizes is:

3k minilogos $= 256 \times 256 \times 3 \times 10^3 = 196$ Mbits = 24.576 Mbytes

3k std logos $= 2040 \times 256 \times 3 \times 10^3 = 1.567$ Gbits = 195.84 Mbytes

3k macrologos $= 2040 \times 2640 \times 3 \times 10^3 = 16.157$ Gbits = 2.02 Gbytes

At least three modern high-end disk drives are possible contenders for the task of storing this quantity of data. These are shown in table B3.

Any of these disk drives could hold all the miniature and standard graphics data. The IBM 3380 could hold all the data for all three sizes of graphics data.

4.5.1 Graphics Retrieval Speed

If it is assumed that a logo is placed in the upper third of the page and is confined to a 1- by 3-inch rectangle, then a printer controller architecture can be proposed that contains a graphics buffer, to be down-

Type:	IBM 3370	Fujitsu M2351	IBM 3380
Diameter:	14-inch	10 1/2-inch	14-inch
Capacity:	571.4 Mbytes	473.6 Mbytes	2.52 Gbytes
Transfer rate:	1859 Kbits/s	1859 Kbits/s	3000 Kbits/s
Price:	unknown	$8500	$100k (about)

Table B3. Candidate disk drives.

loaded from a disk, and a line buffer. During that portion of the page time in which the logo is being printed, the controller takes bit-mapped data from the graphics buffer, combines them with text data, and places them in the line buffer. When the line buffer is full, its contents are then shipped out to the printer on a line by line basis in 8-bit bytes. During the lower 2/3 of the page time, the graphics buffer is not being accessed and a new logo can be down-loaded from disk. This time is (1/1.5) × (2/3) or 444 milliseconds. *The required data rate is then* $\frac{21.6 \text{ Kbytes}}{0.444}$ or 49 Kbytes/s. This is not a stressing requirement for most rigid disk drives, which have total access times (seek time plus latency time) well under 100 ms and data transfer rates around 1 Mbyte/s.

4.5.2 Graphics Compression

A set of five logos has been digitized (captured) by means of the USPS/NOSC Image Capture and Analysis System (ICAS). These logos were digitized at a resolution of approximately 360 by 360 pels/inch and reduced as described previously to a resolution of 180 by 180 pels/inch (see section 4.5).

Each logo was then processed by ICAS software to produce lists of run lengths for the white and black runs in the image area. The tabulated runs were then processed by computing the number of bits required to transmit the logo for each of the four common types of compression algorithms used, as follows:

Variable-length code with 2-bit minimum length

Variable-length code with 3-bit minimum length

4-bit fixed-length code

6:3-bit fixed-length code

The results of these ICAS calculations are shown in table B4. The 2-bit and 3-bit variable-length codes (shown in tables B5 and B6) are clearly superior to the fixed-length codes.

	Code			
Logo	Variable 2-Bit-Min	Variable 3-Bit-Min	Fixed 4-Bit	Fixed 6:3-Bit
Busch	4.62	4.93	3.16	3.77
Teac	6.52	7.01	3.33	5.80
Airpax	5.31	5.53	3.16	2.27
Signetics	3.27	3.44	2.59	2.29
Micromemory Inc	4.53	5.03	3.12	3.74
Average	4.85	5.188	3.072	3.574

Table B4. Compressibility of typical logos.

The rewards of graphics compression for site storage and high-speed retrieval for printing are very significant in terms of disk storage and retrieval speed. Special decoding hardware is required to accommodate decompression. Section 6.1.1 discusses the possible benefits of graphics data compression for communications.

4.5.3 Effect of Relaxing Logo Size and Location Constraints

Consider now that two logos are allowed, each 1 by 3 inches, and that these could be placed anywhere on the page. (The bottom logo could be a signature.) This obviously doubles the storage requirement, which was 64.8 Mbytes for 3000 1- by 3-inch logos. But now the time available to load the logo buffer between pages may be drastically reduced since this buffer must be available for access while the page is being printed. A possible solution is to double-buffer the logo data. That is, while one buffer is being read, another is down-loaded for the next page.

What if full-page graphics, such as those found around the border of some letters, were allowed? The storage requirement for 3000 full-page graphics is $240 \times 240 \times 8.5 \times 11 \times 3000/8$, or about 2 gigabytes. This would tax the

Run Length (elements)	Code Word		Code Word Length
	Address	Remainder	
1	0	0	2
2	0	1	2
3	10	00	4
4	10	01	4
5	10	10	4
6	10	11	4
7	110	000	6
.	.	.	.
.	.	.	.
14	110	111	6
15	1110	0000	8
.	.	.	.
.	.	.	.
30	1110	1111	8
31	11110	00000	10
.	.	.	.
.	.	.	.
62	11110	11111	10
63	111110	000000	12
.	.	.	.
.	.	.	.
126	111110	111111	12
127	1111110	0000000	14
.	.	.	.
.	.	.	.
254	1111110	1111111	14
255	11111110	00000000	16
.	.	.	.
.	.	.	.
510	11111110	11111111	16
511	111111110	000000000	18
.	.	.	.
.	.	.	.
1022	111111110	111111111	18
1023	1111111110	0000000000	20
.	.	.	.
.	.	.	.
2046	1111111110	1111111111	20
2047	11111111110	00000000000	22
.	.	.	.
.	.	.	.
4094	11111111110	11111111111	22
MC	11111111111	111111111OP	22

Table B5. Variable word length RLC code with 2-bit minimum-length code.

Run Length (elements)	Address	Remainder	Code Word Length (bits)
1	0	00	3
2	0	01	3
3	0	10	3
4	0	11	3
5	10	00	4
6	10	01	4
7	10	10	4
8	10	11	4
9	110	000	6
10	110	001	6
.	.	.	.
.	.	.	.
16	110	111	6
17	1110	0000	8
18	1110	0001	8
.	.	.	.
.	.	.	.
32	1110	1111	8
33	11110	00000	10
.	.	.	.
.	.	.	.
64	11110	11111	10
65	111110	000000	12
.	.	.	.
.	.	.	.
128	111110	111111	12
129	1111110	0000000	14
.	.	.	.
.	.	.	.
256	1111110	1111111	14
257	11111110	00000000	16
.	.	.	.
.	.	.	.
512	11111110	11111111	16
Margin Code	111111110		

Table B6. Variable word length RLC code with 3-bit minimum-length code.

storage capacity of even the larger (and more expensive) disk systems. A single full-page logo would require 673 Kbytes. Allowing 100 ms for seek and latency times, the data transfer rate would be 673 Kbytes/[(1/1.5) - 0.1]s, or 1.18 Mbytes/s. This is obtainable on many disk drives. Now, however, the double-logo buffer grows to 2 × 673 Kbytes or 1.4 Mbytes. This is a large amount of high-speed memory. At this point, compression of logo data becomes more desirable.

4.6 GRAPHICS EQUIPMENT INTERFACE

Existing electronics components of the SPOs provide good capability for expansion. The use of the Digital Equipment Corp (DEC) PDP-11 series processors and the UNIBUS offers wide flexibility to expand and upgrade the performance of the SPOs. The expansion of functional capability probably can be accomplished with little impact on daily E-COM message handling operations.

Figure B14, taken from a USPS document, is a block diagram of the SPO electronic hardware configuration. At the bottom of the diagram we have added another printer, shown in the figure as a Delphax. Any other new high-performance printer, such as the HP 2680 or the Datagraphix 9825 laser printers with appropriate interface control units matching the DEC UNIBUS, could be added similarly.

Data streams of ASCII character data are not fast enough to tax the UNIBUS bandwidth appreciably so long as the graphics storage medium is understood to be part of the formatter/controller. Alteration of the residual contents of the graphics storage disk need not require high-speed data interchange over the UNIBUS.

Neither the Delphax printer nor its formatter/controller occupy much floor space. The addition of one or two units at each SPO should not cause a serious space problem. Figure B15 shows a possible installation layout. If the printer equipments selected are HP 2685s or Datagraphix 9825s, a more serious space impact will be encountered.

The USPS must plan for the communications interface as well as the printer interface. If tape interchange is selected to transmit E-COM messages, then a large tape/disk memory complex with direct input to the sorting processor probably will be required.

If lower bandwidth interchanges are being made by landline/microwave or satellite communication on a 24-hour per day basis, then the large tape/disk memory complex accessing the modem and the sorting processor may be similar to the tape interchange architecture.

If the message interchange operating procedure dicates that wideband communications will provide all necessary E-COM message exchange in a few minutes or hours per day, for example immediately after a batch sort, then special random access memory (RAM) elastic buffers may be required to transmit and receive the message traffic.

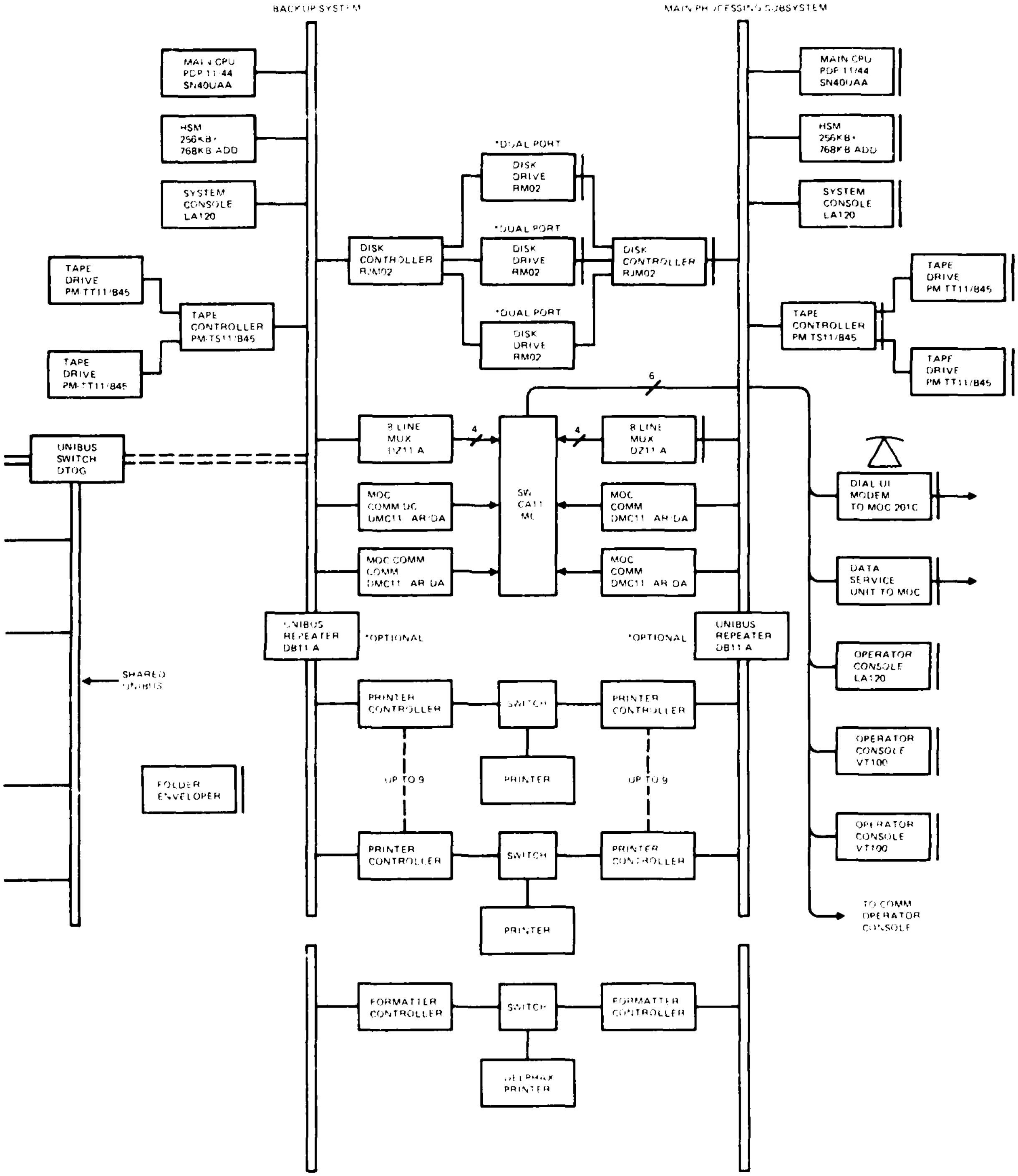


Figure B14. Delphax printer interface to existing E-COM system.

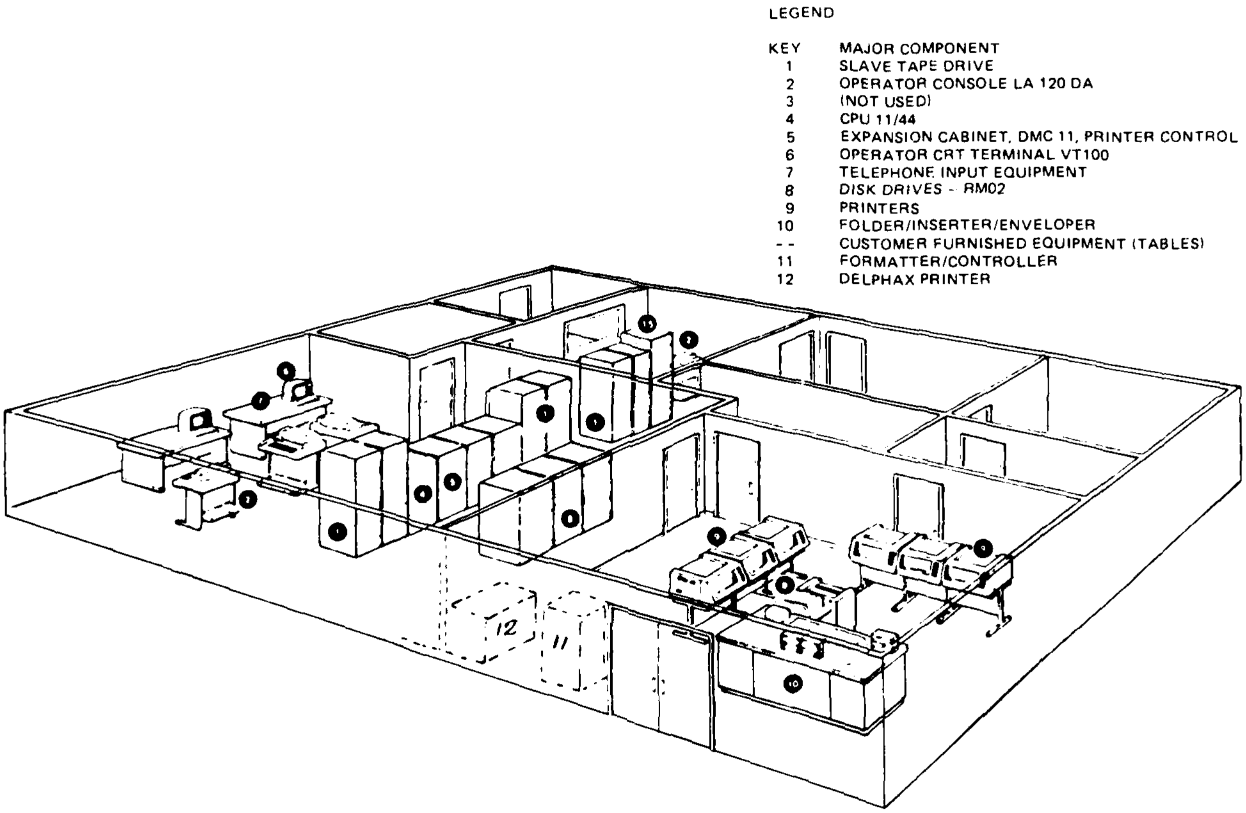


Figure B15. Delphax printer installation within an existing E-COM site.

5 GRAPHICS DIGITIZING WORK STATION DESIGN CONSIDERATIONS

5.1 ASSUMPTIONS

1. Implicit here is the assumption that the customer will submit a camera-ready graphics sample to the work station for digitization and storage. An alternative is for the customer to digitize the logo in some standard format. The latter option will not be considered here.

2. The E-COM message format will specify an area, say 2 inches by 4 inches, reserved for logos. The logo may occupy part or all of this space. The customer will specify the logo size and location within the allowed space. This specification can accompany the submission of the sample logo or can be made in real time by a customer representative during the digitizing process. The work station will allow interactive placement and scaling of the logo within the allowed area.

3. Editing of selected pels within the digitized logo will be both necessary and possible.

4. The sample logo will be digitized by some scanning system. A working assumption here is that a digitizing camera such as Datacopy C322 will used. This device has a linear CCD array which moves across the focal plane of the camera. Scan time is about 2.3 seconds.

5. The work station will allow logos to be digitized to any reasonable square resolution. This design specification will allow future printers to be accommodated, so as to avoid binding the E-COM system to a particular printer such as the HP 2680.

6. No assumption is made here regarding nonsquare resolutions. The capacity to digitize to nonsquare resolutions is treated as a design option, and the difficulty of doing this is discussed.

5.2 WORK STATION OVERVIEW

For discussion, two possible hardware configurations are shown in figures B16 and B17. Both feature a camera stand, a frame store memory, thresholding circuitry, a display, and printers. In figure B16 the 8-bit video data are thresholded and stored in a 1-bit frame store memory. The image must be rescanned with every threshold adjustment. The system of figure B17 includes an 8-bit deep frame store memory. With this, the threshold can be adjusted without rescanning. In both systems, real-time adjustment of camera stand parameters and editing of the digitized graphics are possible. Interpolation within the 1-bit or 8-bit frame store memory might be a system feature.

5.2.1 Camera Stand

This apparatus contains a digitizing camera and control electronics, assumed to be similar to the Datacopy C322. The camera is directed at an illuminated logo and has several degrees of freedom:

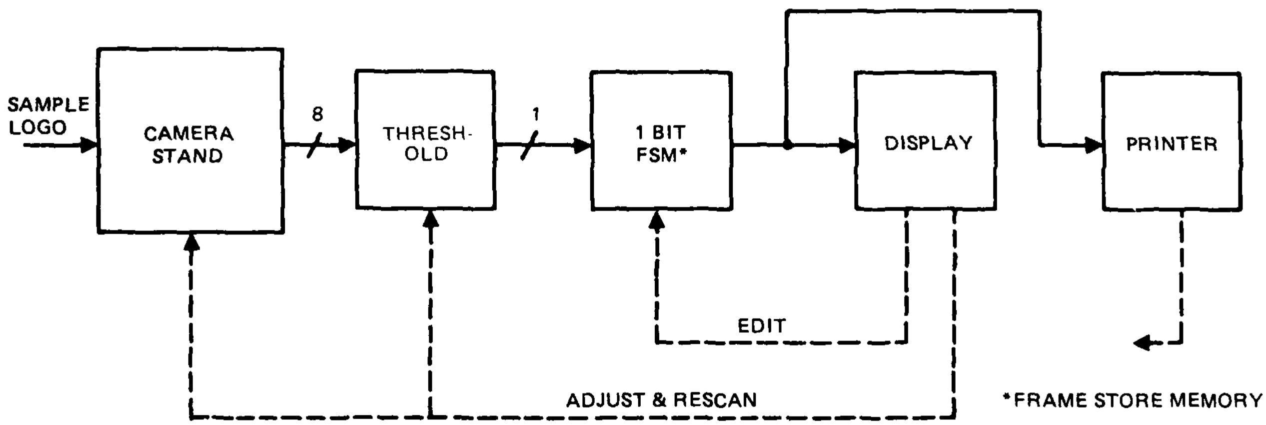


Figure B16. Graphics work station with 1-bit deep frame store memory.

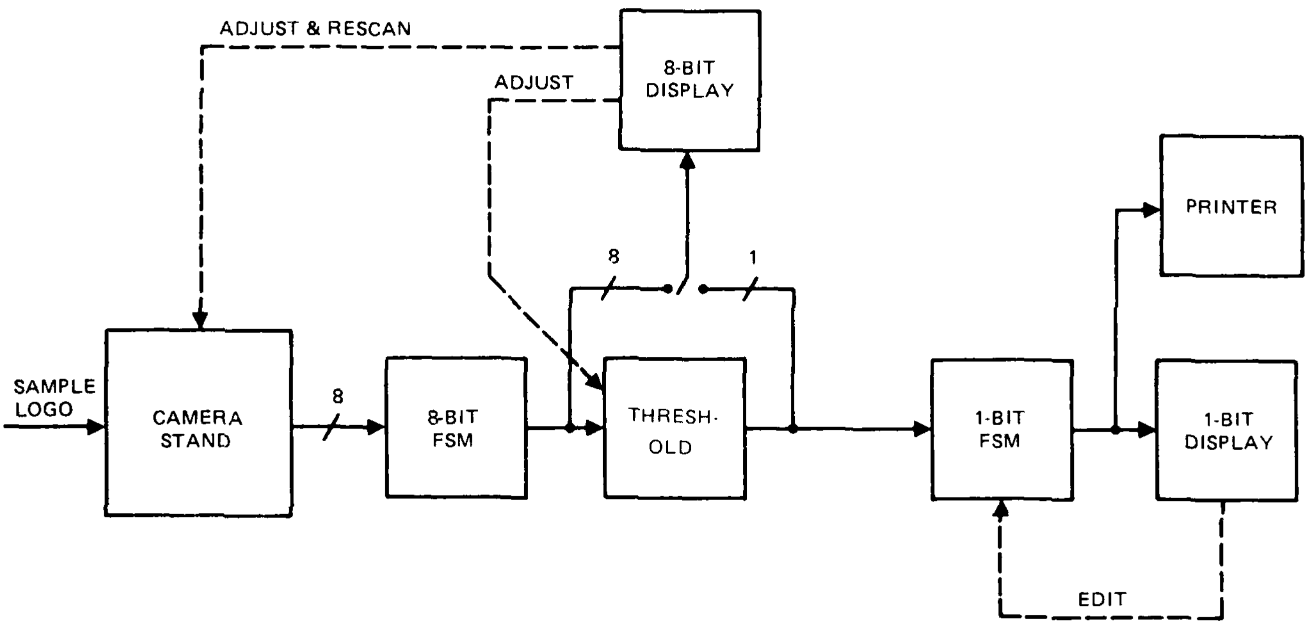


Figure B17. Graphics work station with 8-bit deep frame store memory.

1. Camera aperture
2. Camera focus
3. Camera height above logo (Z)
4. Logo position (X)
5. Logo position (Y)
6. Logo orientation (θ)
7. Logo illumination

For each logo and resolution, some of these parameters may be varied. It may also be possible to vary the rate at which the CCD array sweeps across the focal plane of the camera or the rate at which the CCD array is sampled.

5.2.2 Thresholding

This is necessary to reduce the 8-bit pels from the digitizing camera to bilevel pels for printing. Since the intensity variations at the edges within a logo image are ramp functions, the chosen threshold determines the location of borders within the logo and thus the size of the black and white areas. It is necessary to adjust the threshold for each sample logo to accommodate variations in the reflectance of its dark and light portions. The thresholding circuits of figures B16 and B17 can be as simple as an 8-bit latch and comparator. Alternatively, in figure B16, the threshold could be fixed at, say, one-half the dynamic range, and the variations in reflectance could be balanced by adjusting the camera aperture or the illumination intensity.

5.2.3 Frame Store Memory

This stores the digitized image. It can be 1 bit or 8 bits deep. An 8-bit frame store memory allows threshold updates to occur at video refresh rates, whereas a 1-bit frame store memory requires that the logo be rescanned for each update.

If the camera height is adjusted to select different scanning resolutions, then a refocus is necessary. It may be easier to refocus while observing an 8-bit image than while observing a 1-bit image. With either, however, a rescan is necessary with each focus adjustment.

Interpolation may be used to achieve resolutions different from those scanned. An 8-bit frame store memory will allow this to be done within the grey level image. However, binary interpolation in the 1-bit frame store memory may be satisfactory if the original scan density is high enough.

5.2.4 Display

The image display provides feedback to the operator during adjustment of the camera stand and threshold and while editing the digitized image. To view a logo scanned at high resolution (super resolution), a display such as the Datacopy D515 may be necessary. This system can store and display a bit-mapped image of 1728 by 2200 pels.

It will be necessary to adjust the size, position, and orientation of the logo relative to the space allowed for it in the E-COM message format. One way to represent this relationship is to display on the digitized logo a superimposed rectangular window, corresponding to this allowed space.

5.2.5 Image Restoration

Some modification of the digitized logo will certainly be required to remove artifacts (figure B18). One type of artifact consists of the steps which may be found along normally vertical or horizontal edges. Another is the random black or white pels (bumps or depressions) also found on edges. Still another artifact is random black (white) pel-islands within white (black) areas. Restoration may also be necessary for aesthetic purposes.

5.2.6 Printers

A printout of the logo on the printer for which it was digitized will indicate the success of the digitizing and editing effort. It may suggest a further iteration. In addition, the hard copy could be provided for approval by the customer's management.

It may also be desirable to generate an enlarged hard copy of the digitized logo on a graphics plotter. Thus individual pels could be identified and marked for modification.

5.3 DESIGN ISSUES

5.3.1 Nonsquare Printer Resolution

The decision to accommodate printers with nonsquare resolutions will impact work station design. While there are no known future nonimpact printers with nonsquare resolutions, there is at least one present printer which is nonsquare: the Datagraphix machine, which has a resolution of 180 by 144 pels/inch. In addition, most impact printers are nonsquare. For example, the Printronix P300 is 60/120 by 72.

There are two ways to digitize to nonsquare resolutions: either the acquisition process itself can be made to produce nonsquare pels or interpolation within a square pel array can yield a nonsquare array.

Assuming that a digitizing camera such as the Datacopy C322 is used, it may be possible to vary the scan density in the Y-direction either by varying the rate of movement of the CCD array across the focal plane while keeping the sample rate fixed or by fixing the rate of movement and varying the sample rate. Either would require precise control of the appropriate rate to avoid distortion in the printed image. In addition, the integration time at the CCD photosites would be affected, thus impacting other camera parameters. More study of this option is necessary.

Alternatively, the camera can function as designed, producing a square array, and interpolation can be done within this array. The C322 digitizes [illegible] 8-bit precision. Either the 8-bit image could be thresholded and [illegible] interpolation done in the bilevel image or interpolation could be done [illegible] 8-bit image and the result thresholded. With binary interpolation [illegible] desirable to start with an original resolution several times [illegible] resolution) than the final. High resolution is possible with the [illegible] which digitizes to 1728 by 2200 pels. If interpolation in the [illegible] to be done, the logo need only be digitized to moderate [illegible] for some special cases, the computational load [illegible] significant.

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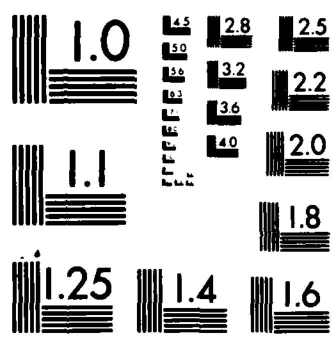

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

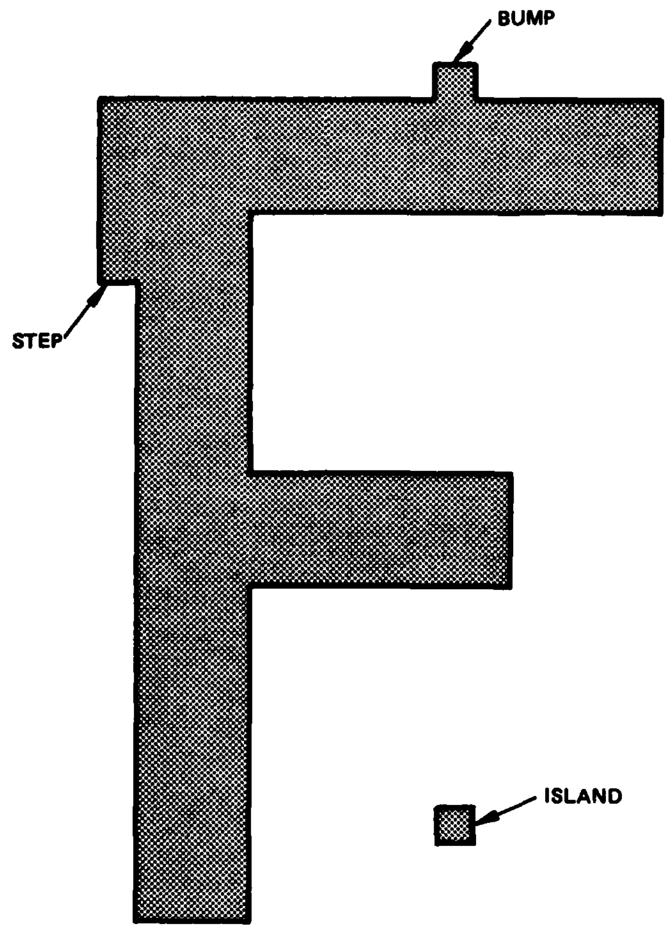

Figure B18. Typical artifacts in a bilevel image.

Another problem with nonsquare resolutions is in displaying the digitized image. Logos would appear distorted on nominally square raster-scan displays. On some monitors, this apparent distortion could be corrected by the height and width controls.

5.3.2 Frame Store Memory

Another fundamental issue is the depth of the frame store memory: 1 bit versus 8 bits.

8-bit advantages:

a. Allows threshold adjustments at video refresh rates.

b. Focus adjustment may be easier while viewing an 8-bit display.

c. Allows higher precision interpolation within the grey-scale image.

1-bit advantages:

a. Less expensive memory.

b. Makes feasible super-resolution scanning, i.e., digitizing to high resolution, say 600 per inch or so, for the purpose of interpolation.

5.3.3 Interpolation

Interpolation can be used to achieve resolutions other than the scanned resolution, for either square or nonsquare sampling. Two types--binary and full precision--are considered here.

a. Bilevel interpolation. With bilevel interpolation, one bilevel array is derived from another. Computationally, it is quite simple. For nearest-neighbor bilevel interpolation, two integer multiplications are required per element in the output array. However, it is desirable that the original image be digitized to a relatively high resolution (super resolution) to reduce error in the location of edges in the output image. This then will impact storage and display requirements. Annex B discusses bilevel interpolation.

b. Full-precision interpolation. There are numerous ways of doing interpolation. The most trivial and least effective is the nearest neighbor method. Bilinear interpolation in which a hyperbolic paraboloid is fitted to the four nearest neighbors provides an improved interpolation value for brightness. There is also interpolation by convolution. With this, a symmetric three-dimensional surface (convolution function) is positioned over the input array at the point at which interpolation is desired. The output pel value is the sum of the products of the brightness value of each intercepted input pel and the value of the convolution function at that point. Figure B19 shows a very simplified one-dimensional example. In the minification algorithm used in the NOSC ICAS, a rectangular convolution function is used. For the special case where the input resolution is an

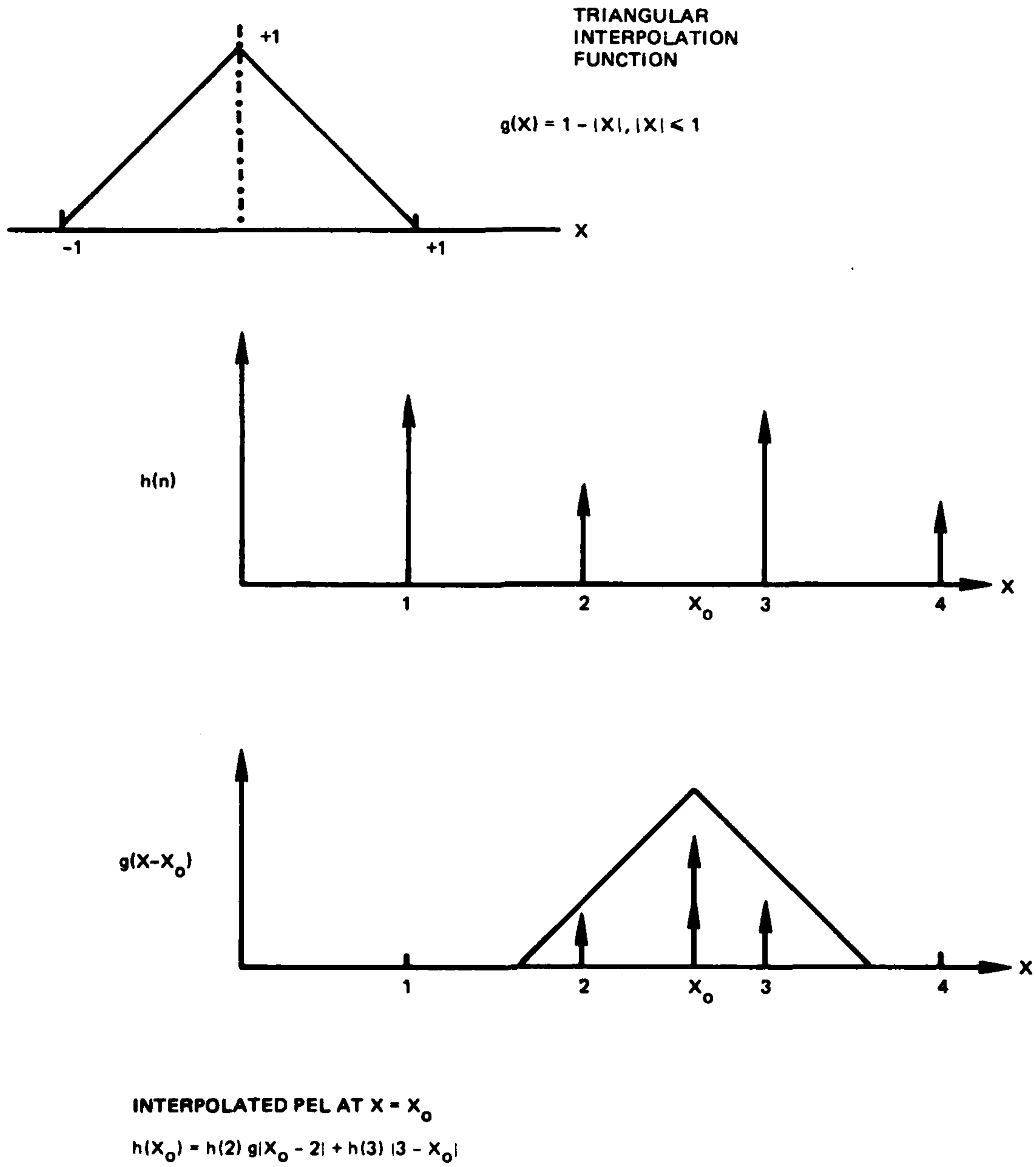

Figure B19. Example of a simple one-dimensional convolution.

integral multiple of the output resolution, this is computationally efficient. Other popular convolution functions are cubic spline approximations (bounded) of the sinc function (sin(x)/x), which is the perfect convolution function but is infinite in domain and involves a transcendental function. All of these methods except nearest neighbor interpolation are computationally burdensome and, of course, require a frame store memory of some depth. In addition, unless the original resolution is several times larger than the output resolution, a separate memory allocation is generally required for the output image. That is, the interpolation cannot be performed in place.

5.3.4 Thresholding

Options available for thresholding depend on whether a 1-bit or an 8-bit frame store memory is employed.

1-bit frame store memory

1. Adjust a digital threshold while holding illumination and camera aperture constant. Pels having intensities equal to or above this threshold are declared white. This adjustment must be done on a scan-by-scan basis.

2. Fix the threshold at, say, the most significant bit (MSB), and vary camera aperture or illumination intensity. This would require no thresholding circuit at all, but it must also be done on a scan-by-scan basis.

8-bit frame store memory

1. Adjust a digital threshold. It is possible to do this at video refresh rates.

2. Allow a digital threshold to be set in software. Algorithms to do this would require some development effort.

5.3.5 Logo Sizing and Positioning Without Interpolation

In the absence of interpolation, there is a fixed relation between the sample logo size, the camera height and focus (scanning resolution), and the printed logo size and resolution. There are essentially two options:

a. Require that the printed logo size be defined by the sample logo size. For instance, assume that a 2- by 4-inch space is allocated for logos in the E-COM message and that the customer is required to size his sample logo relative to a 4- by 8-inch rectangle. In other words, the customer defines the size of the printed logo by scaling his sample logo, in this case by a factor of 2. For a printer resolution of say 300 pels per inch, the scanning resolution is done at 150 per inch. With this option, there is a specific camera height and focus (scanning resolution) adjustment for each printer resolution, and readjustment of the camera height and focus is not required for each new logo and printer resolution. However, this must be weighed against inconvenience to the customer, who cannot submit just any logo of reasonable size.

b. A second option is to require only that the sample logo size fall within the limits of the camera stand. In general, larger sample logos are preferred to reduce the effects of imperfections such as slightly wiggly "straight" lines. For each logo and printer resolution, separate camera height and focus adjustments are necessary. These could be made while viewing a display of the scanned logo superimposed with a window representing the space allowed for the printed logo. For instance, if a 2- by 4-inch space is allowed for the printed logo and the printer resolution is 200 pels per inch, then the window would be 400 by 800 pels. This dynamic scaling of the logo could be combined with logo positioning within the allowed message space. Either the sample logo could be moved about the camera stand while the operator watches the displayed logo move relative to window, or the window could be moved about the display with the sample logo left stationary. In either case, logo orientation on the easel must be adjusted manually.

5.3.6 Logo Sizing and Positioning With Interpolation

With interpolation, the following can all be arbitrary: the sample logo size, its position in the camera stand, the camera height and focus (scanning resolution), the size and position of the printed logo, and the printer resolution. For a printer of any resolution, within limits, a logo of any size can be placed anywhere within the camera field of view (properly oriented) and the camera height and focus can be fixed.

The scanned logo can be displayed at the scanned resolution and a window can be scaled and moved about the display to scale and position the printed logo. The dimensions of the window in scanned pels relative to its dimensions in printed pels define the required interpolation.

5.3.7 Hard-copy Output

For each printer type, it would be desirable to provide the customer with a printed sample of the digitized logo as it would appear in the E-COM message. An option is to generate a large-scale logo hard copy. This could be done in one of two ways:

a. One of the printers used to produce a sample printed E-COM logo could also print a scaled-up version. For instance, if the logo space is 2 by 4 inches, a 2X logo could be printed in a 4- by 8-inch space.

b. Alternatively, a 36-inch graphics plotter could be used. This would print pels large enough to be seen easily.

5.4 DESIGN OPTIONS

There are numerous paths through the sets of options discussed. A fundamental work station specification will refer to printer resolution. If nonsquare resolutions are allowed, are they to be achieved through interpolation or through the use of a nonsquare scanner? If interpolation is used, will it be bilevel or higher precision? The depth of the frame store memory is also a driving function. Fig B20 shows a decision tree. Table B7 summarizes four design options thought to be reasonable.

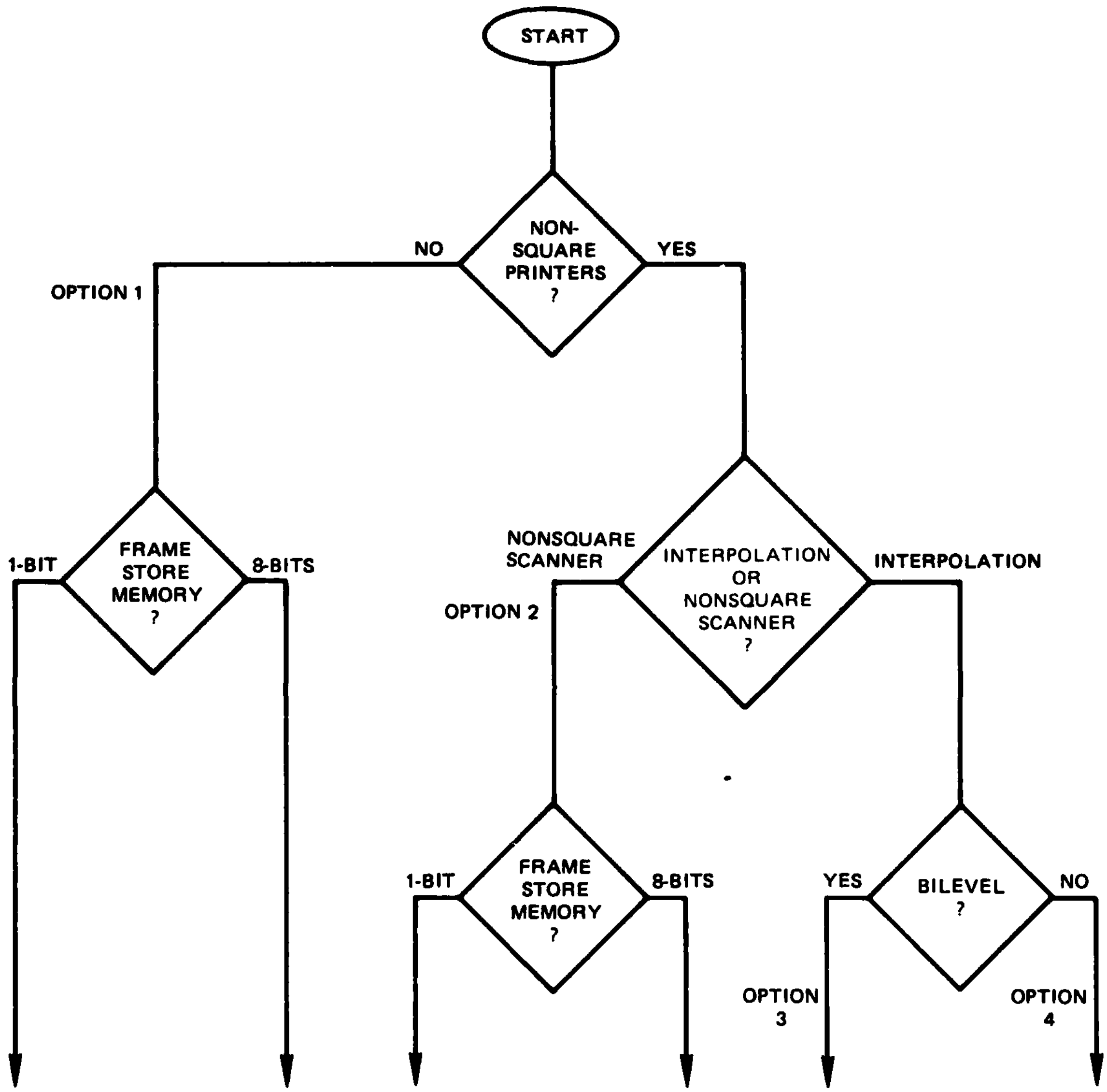

Figure B20. Design decision tree for graphics conversion subsystem.

Option	1	2	3	4
Accommodate nonsquare printers	No	Yes	Yes	Yes
Nonsquare display required	No	Yes	Yes	Yes
Interpolation	No	No	Yes, binary	Yes, 8 bits
Super-resolution scanning	No	No	Yes	No
Nonsquare scanner required	No	Yes	No	No
Frame store bit depth	1 or 8	1 or 8	1	8
Threshold at video rate	No Yes	No Yes	No	Yes
Sample logo size	specified	arbitrary	arbitrary	arbitrary
Adjustment of camera height and focus required	Yes, to preset value	Yes	No	No
Need to rescan for new printer resolution	Yes	Yes	No	No

Note: Arrows indicate consequences.

Table B7. Graphics conversion subsystem design options.

5.4.1 Option 1. Square Printer Resolution

Neither interpolation nor a nonsquare scanner is required, and there is no need for a nonsquare display. Suboptions are the depth of frame store memory and whether or not the sample logo size will be specified. For each logo and printer resolution, it will be necessary to reset camera height and focus. These can be preset to given values if the logo size is specified. Readjustment of the threshold is necessary with each camera height setting and, as with the other options, a separate editing process is required for each resolution. Figures B16 and B17 illustrate possible system configurations under this option for 1-bit-deep and 8-bit-deep frame store memories.

The following is a possible procedure for digitizing a sample logo under option 1. It assumes that the input logo size is not specified and that a 1-bit frame store memory is used.

1. Place sample logo in camera stand.

2. Enter printer type. (The printer's resolution, along with the maximum allowable printed logo size, defines the size, in pels, of the logo window in the display.)

3. Enable system to scan the sample logo continuously, refresh the frame store memory, and display its contents. With the Datacopy C322, this can occur about once every 3 seconds.

4. Adjust camera height (printed logo size) and focus. Adjust logo orientation, window position, and threshold.

5. Stop scan and refresh cycle.

6. Edit displayed logo.

7. Store and print contents of window.

8. Go to step 2 for next printer type.

5.4.2 Option 2. Nonsquare Printer and Nonsquare Scanner

Here, a nonsquare printer resolution is matched with a similarly nonsquare scan resolution. The scenario is similar to that outlined for option 1 except that selecting a printer type defines both the window size and the ratio of horizontal to vertical scan resolution. Assuming a camera like the C322, this could be accomplished by controlling the scan or sample rate. (At this time, we do not know whether this can be done easily.) If the selected printer has nonsquare resolution, it will also be necessary to adjust the height-to-width ratio of the display.

5.4.3 Option 3. Nonsquare Printer Resolution, 1-bit Frame Store Memory and Interpolation

With this configuration, a nonsquare print resolution is obtained by performing bilevel interpolation into a 1-bit-deep frame store memory.

Super-resolution scanning is desirable. Under options 1 and 2, it is necessary to readjust camera height, focus, and threshold for each logo and printer resolution. But since interpolation is available under this option, scanning can always be done at one standard (high) resolution and camera height and focus need not be adjusted. Only one orientation and threshold adjustment is required per logo. The displayed window can be positioned and scaled under operator control. The size of the display window, in scanned pels relative to the size of the logo space in printed pels, defines the scaling to be achieved by interpolation.

A possible procedure under option 3 follows:

1. For a previously scanned (at super resolution) logo, recall from archive and go to step 9.
2. Place sample logo in camera stand.
3. Put system in scan and refresh mode.
4. Adjust logo orientation and threshold.
5. Exit scan and refresh mode.
6. Position and scale display window.
7. Store high-resolution logo.
8. Enter printer type.
9. Do interpolation and display result.
10. If printer type is nonsquare, adjust display height and width to remove distortion.
11. Edit.
12. Store and print.
13. Go to step 9 for next printer type.

5.4.4 Option 4. Nonsquare Printer Resolution With 8-bit Interpolation

Here, 8-bit interpolation is performed. This may be slow, depending on the processor and algorithm, but super-resolution scanning is not needed. A separate threshold adjustment probably will be needed after each interpolation. A procedure might be as follows:

1. For a previously scanned (at super resolution) logo, recall from archive and go to step 8.
2. Place sample logo in camera stand.
3. Put system in scan and refresh mode.

4. Set threshold and adjust orientation on a bilevel image. (It will be easier to orient the sample logo while viewing a bilevel image, as staircase patterns will be easily visible.)

5. Exit scan and refresh mode.

6. Position and scale display window.

7. Store scanned logo.

8. Enter printer type.

9. Do interpolation (you may have time for a cup of coffee or even lunch) and display results.

10. Set threshold.

11. Edit thresholded image.

12. Store and print.

13. Go to step 8 for next printer type.

5.5 WORK STATION DESIGN RECOMMENDATIONS

Option 3 appears attractive. Recall that this option uses bilevel interpolation in a 1-bit frame store memory to obtain various print resolutions, either square or nonsquare. This offers flexibility and simplicity. For each logo, only two manual adjustments are needed: logo orientation and threshold. All other operations occur in software. A possible disadvantage with this approach is that high-resolution storage and display are required. However, the two Datacopy products discussed, the C322 camera and the Model 521 frame store memory and display, can provide this at reasonable cost.

Figure B21 shows a possible system configuration using option 3. This system is driven by a microcomputer with its own resident low-resolution display. The high-resolution display is used for focus, logo orientation, and thresholding adjustments and for framing the scanned logo in the print window. The microcomputer's memory and low-resolution display contain the print matrix for editing. This is loaded by interpolating into the high-resolution matrix contained in the frame store memory. As a default, interpolation need not be used at all and the low-resolution microcomputer memory can be loaded directly from the high-resolution frame store memory.

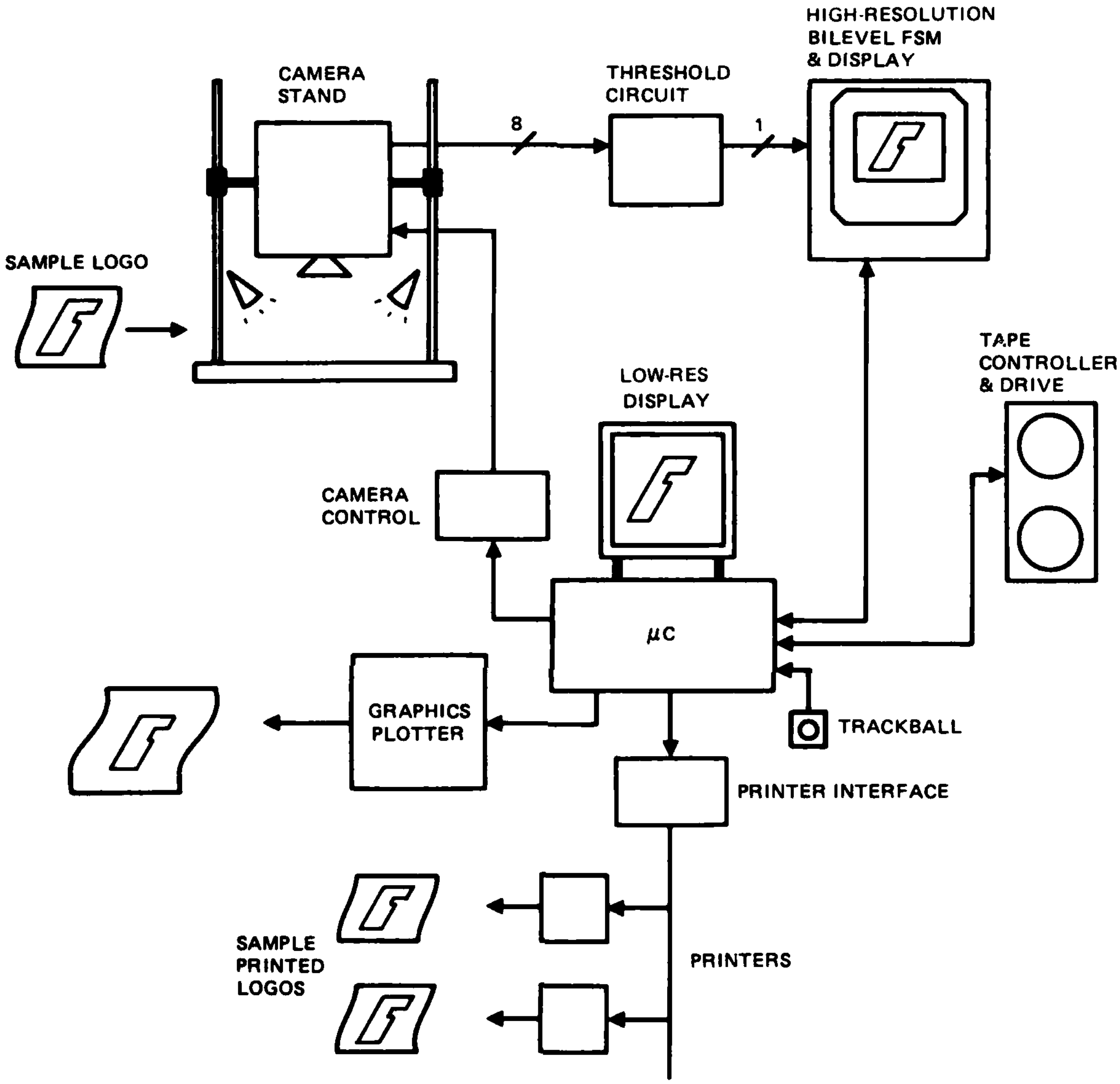

Figure B21. Candidate system configuration using option 3.

6.0 E-COM COMMUNICATIONS

The volume of E-COM mail is expected to increase to 10 billion pieces per year during the fifth year of operation, as shown in figure B3.

If the volume of messages to be transmitted from all 25 SPOs were equal, then an annual acceptance and delivery rate of 400 million pieces would be achieved by each SPO at the end of the fifth year. Probably the acceptance and distribution rate will be other than equal for each SPO and will vary greatly, just as current first-class letter volumes vary now. For this study, it is assumed that there are two SPOs that handle twice the volume of the geometric mean volume and that there are two SPOs that handle half the mean volume (2:1:1/2). Under this distribution, the SPO traffic might grow as shown in table B1.

An example might be as follows

Assume:

Comm system is Bell system T-1 line at 1.544 Mb/s

Transmitting SPO = Detroit
Year = first year
Volume = 128 000 pieces/day

Then, using equation 1:

$$T = 6.552 \times 10^3 \times \frac{1.28 \times 10^5 \text{ pcs/day}}{1.544 \times 10^6 \text{ b/s}}$$

$$= 543.17 \text{ s}$$

$$= 9.05 \text{ min}$$

Since the volume is expected to increase ten-fold in 5 years, the time will increase to 9.05 min × 10 = 1.51 hours during the fifth year.

6.1 DATA COMPRESSION/EXPANSION

6.1.1 Effects of Logo/Signature Compression on Communications

During the investigation of the microprocessor formatter for the Delphax printer, some serious design problems arose regarding the retrieval of graphics information from a storage medium such as a high-performance disk.

Transmission and storage of graphics data benefit from the use of compression. An intuitive but not yet verified premise is that the highest compression ratio for graphics data will result from a two-dimensional encoding algorithm similar to the modified READ code (MRC) defined in section 4.2 of Electronic Industry Association (EIA) recommended standard RS-465 (now also Federal Standard 1062, 3 April 1981). This coding scheme employs a ratio

of lines of modified Huffman code (MHC) to several lines of differential encoding data whose values are predicated on current line pel values and previous line pel values. The ratio of lines transmitted per group to MHC lines transmitted is the "K" factor. For example, if one transmitted MHC line is followed by three lines of two-dimensional coding, the value of K = 4.

The table of terminating codes defined in table 1, paragraph 4.1, of RS-465/Fed Std 1062 provides different code words for white runs and black runs. This is because with text and ruled form facsimile data, black runs longer than a few pels are seldom expected. With graphics data, scanned at 240 by 240 pels/inch, black runs as long as 512 or 1024 pels in length may be commonly encountered. Therefore, the "standard" MHC used for text probably should be modified further for maximum compressibility. For example, the white run length table (with modifications) could be used for both white and black runs in a modified MHC (M^2HC) table. Tables B5 and B6 of this report are taken from the Second Annual Report, Advanced Mail Systems Scanner Technology, NOSC Technical Report NELC TR-2020, October 1976. These tables are candidate examples of compression schemes that could be used for either black or white runs.

Another high-compression scheme for logo information (but not for signatures) might be combined symbol matching (CSM). Block characters of black pels in a matrix of perhaps 16 by 16 pels that form simple rectangles and triangles might be used to fill most of the massive black bulk areas. Edge detail areas failing to match any designated symbol by default would be transmitted and stored by a second encoding scheme.

These high-compression algorithms greatly improve communication bandwidth, information storage capacity, and information storage and retrieval (ISAR) rates. They also greatly compound the complexity of the real-time decoding hardware and software used to generate the page bit-map data needed to provide raster-oriented data to the printer.

In the analysis of transmission time required to send graphics data to the SPOs for storage, the graphics traffic is only a small percentage of the text message traffic. We conclude that in the scenario we examined, graphics compression for the conservation of communication bandwidth is not economically significant.

6.1.2 Text Character Data Compression

The study of text character data compression was initially included as a subsection of this report. Because of the high-priority interest by the USPS, this portion of the work was partitioned out of this report. It was requested as an accelerated deliverable. The results of the study were submitted to the USPS as a letter report, "Text Character Compression Study," 24 December 1982.

The study included a discussion of null suppression, pattern substitution, Huffman coding, and alternate compression methods. Also included was a brief investigation of possible text compression cost savings.

It was difficult to reach definite conclusions regarding the benefit of text compression. Available literature reports compression ratios of about 1.4:1 and no higher than 1.5:1. The NOSC study results gave about 1.35:1.

NOSC results were obtained by using available data for the probability of occurrence of characters. Some assumptions were made since no data could be found that supplied probabilities for all 128 characters of the ASCII set.

For the short cost tradeoff example calculation, it appeared that for the communication aspect, text compression offered only marginal benefits, if any. Text compression could save perhaps 30% of the SPO text storage requirement at the expense of adding compressor/decompressors at each interface to text message memory.

6.2 LANDLINE/MICROWAVE COMMUNICATIONS

An excellent reference on landline/microwave communications as well as satellite communications for USPS applications was submitted to the USPS in June 1975.* Although this document addressed the EMSS requirements, the scope of the study is nevertheless highly applicable to E-COM.

Some formats for inter-SPO communication networks are shown in figure B22. Figure B22a shows all the SPOs daisy-chained to a single dedicated network such as Bell type T4-M digital cable, capable of 274 Mbits/s. Such a cable system for the distribution of data in the continental US (CONUS) is hardly practical from the geographic standpoint. If affordable, such a cable system could provide some good system advantages.

Operated in the time division multiple access (TDMA) mode, each SPO could be given preprogrammed time slots, in accordance with traffic load, in which to transmit all outgoing E-COM traffic, either once or several times during the day. Except for local-destination mail, outgoing traffic need not be sorted since all 24 nontransmitting SPOs can remain on the net in the receive mode and can accept all transmitted traffic destined for ZIP codes within each SPO's geographical distribution area.

To determine the usage factor of a cable network operated in this fashion, the transmit time can be calculated by using previously derived equation 1. At the end of the first year:

$$T = 6.552 \times 10^3 \times \frac{D}{B}$$

$$= 6.552 \times 10^3 \times \frac{10^9 \text{ messages}}{\text{year}} \times \frac{1 \text{ year}}{300 \text{ days}} \times \frac{1}{274 \times 10^6 \text{ b/s}}$$

$$= 79.71 \text{ s/day}$$

$$= 1.328 \text{ min/day}$$

---

* Proposal to USPS for System Definition and Evaluation Study for Electronic Message Service Systems, Section 5, RCA proposal 922002-A, RCA Govt and Comml Systems, Camden, NJ, 23 June 1975.

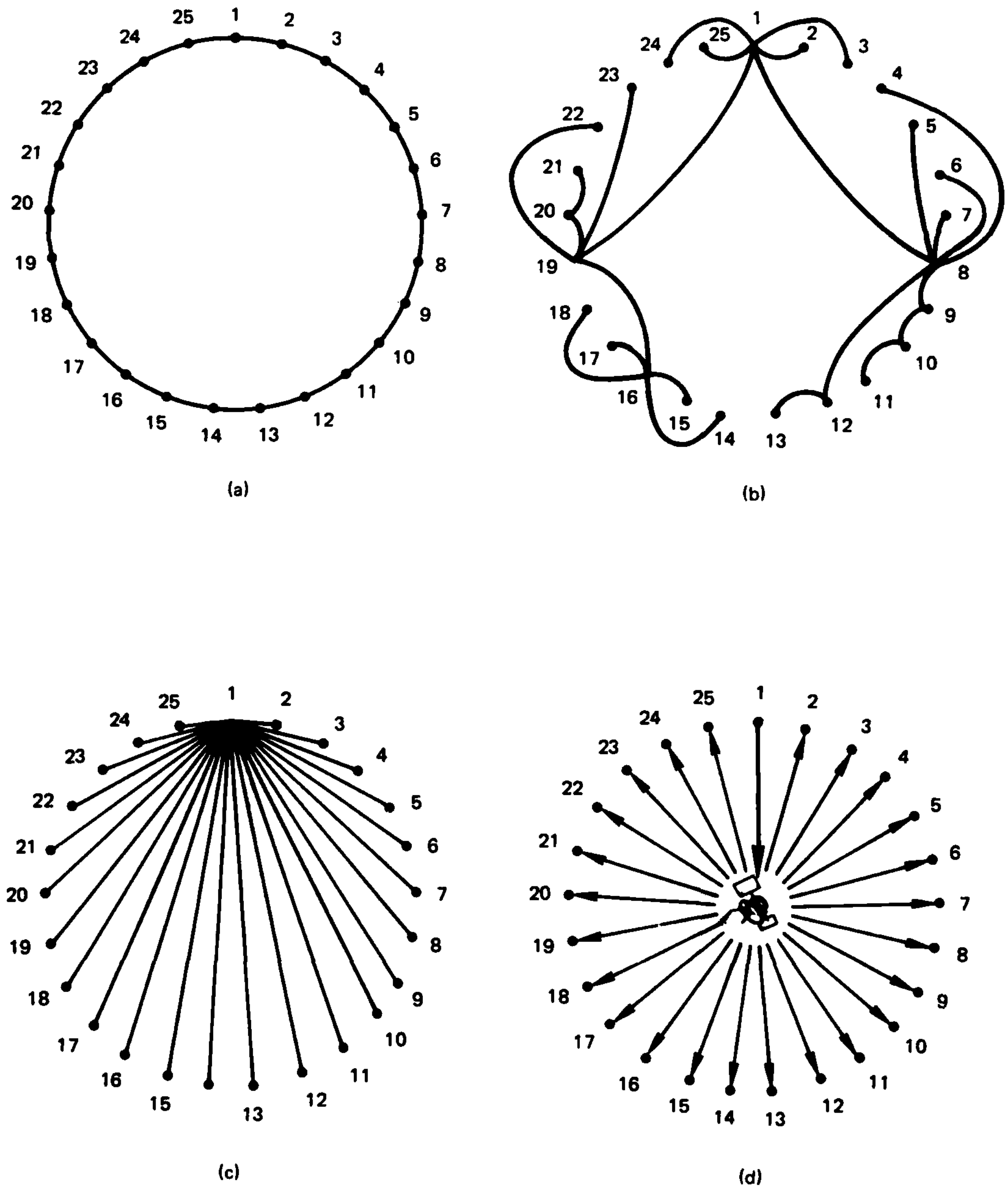

Figure B22. Candidate USPS network types for E-COM.

Then at the end of the fifth year:

$$T = 6.552 \times 10^3 \times \frac{10^{10}\ \text{messages}}{\text{year}} \times \frac{1\ \text{year}}{300\ \text{days}} \times \frac{1}{274 \times 10^6\ \text{b/s}}$$

$$= 13.285\ \text{min/day}$$

It would be advantageous for a SPO to partition the direct customer input E-COM mail into only two categories just before the inter-SPO exchange cycle begins. One category would be the intra-SPO messages not requiring transmission to other SPOs. The other category requires inter-SPO message exchange. No other internal sorting is needed until the inter-SPO message exchange is completed. The first major sorting function is accomplished during the listening and selective acquisition process during the inter-SPO exchange period. After the 13-minute exchange, all resident E-COM messages can be sorted only once and assigned to printer queues.

A second landline network, one having a more realistic configuration for CONUS applications, is shown in figure B22b. Perhaps SPO-1 is a midcontinent office such as Detroit. Major trunking facilities might lead to San Francisco (SPO-19) and New York City (SPO-8). Advantages of this network are less cable, less redundancy, yet more fail-soft capability. For example if the main trunk, SPO-19 to SPO-1, were to fail, the western US and midwest/eastern US could continue to transmit all pertinent messages among available geographic destinations. One airmail package of tapes sent in each direction between San Francisco and Detroit would exchange all remaining daily message traffic that could be forwarded by SPO-19 and SPO-1.

Very little transmission time would be saved by having presorted the messages before initiating the interchange of message traffic between accessible adjacent SPOs. The time saved is dependent on the topology of the network.

The third network type, shown in figure B22c, is the most elaborate. This transmission scheme requires a network of 300 available paths between pairs of SPOs to complete the interchange. Using this type of network, the 25 SPOs are sequentially paired off to produce twelve simultaneous two-way exchange paths. (One SPO is idle.) After the two-way message traffic has been exchanged between the 12 assigned pairs, a new set of SPO pairing assignments is made and messages for the new paired destination SPOs are exchanged. A total of 25 sequences of 12 pairings are required to ensure that all SPOs have had an interchange connection with each other. A sample set of pairing assignments is shown in table B8.

A principal advantage of this configuration is that it requires the minimum transmission time for a land-based network to complete the daily traffic schedule.

There are some disadvantages of this network type. We have assumed that two of the SPOs are super-SPOs, each having twice the volume of the geometric

1	2	3	4	5	6	7	8
25-1	25-2	24-1	25-3	23-1	25-4	22-1	25-5
24-2	24-3	23-2	24-4	22-2	24-5	21-2	24-6
23-3	23-4	22-3	23-5	21-3	23-6	20-3	23-7
22-4	22-5	21-4	22-6	20-4	22-7	19-4	22-8
21-5	21-6	20-5	21-7	19-5	21-8	18-5	21-9
20-6	20-7	19-6	20-8	18-6	20-9	17-6	20-10
19-7	19-8	18-7	19-9	17-7	19-10	16-7	19-11
18-8	18-9	17-8	18-10	16-8	18-11	15-8	18-12
17-9	17-10	16-9	17-11	15-9	17-12	14-9	17-13
16-10	16-11	15-10	16-12	14-10	16-13	13-10	16-14
15-11	15-12	14-11	15-13	13-11	15-14	12-11	1-4
14-12	14-13	13-12	2-1	25-24	3-1	23-25	2-3

9	10	11	12	13	14	15	16
21-1	25-6	20-1	25-7	19-1	25-8	18-1	25-9
20-2	24-7	19-2	24-8	18-2	24-9	17-2	24-10
19-3	23-8	18-3	23-9	17-3	23-10	16-3	23-11
18-4	22-9	17-4	22-10	16-4	22-11	15-4	22-12
17-5	21-10	16-5	21-11	15-5	21-12	14-5	21-13
16-6	20-11	15-6	20-12	14-6	20-13	13-6	20-14
15-7	19-12	14-7	19-13	13-7	19-14	12-7	19-15
14-8	18-13	13-8	18-14	12-8	18-15	11-8	18-16
13-9	17-14	12-9	17-15	11-9	17-16	10-9	8-1
12-10	16-15	11-10	6-1	25-20	7-1	25-18	7-2
25-22	5-1	25-21	5-2	24-21	6-2	24-19	6-3
24-23	4-2	24-22	4-3	23-22	5-3	23-20	5-4

17	18	19	20	21	22	23	24	25
17-1	25-10	16-1	25-11	15-1	25-12	14-1	25-13	13-1
16-2	24-11	15-2	24-12	14-2	24-13	13-2	24-14	12-2
15-3	23-12	14-3	23-13	13-3	23-14	12-3	23-15	11-3
14-4	22-13	13-4	22-14	12-4	22-15	11-4	22-16	10-4
13-5	21-14	12-5	21-15	11-5	21-16	10-5	21-17	9-5
12-6	20-15	11-6	20-16	10-6	20-17	9-6	20-18	8-6
11-7	19-16	10-7	19-17	9-7	19-18	8-7	12-1	25-14
10-8	18-17	1-8	10-1	25-16	11-1	25-15	11-2	24-15
25-18	9-1	25-17	9-2	24-17	10-2	24-16	10-3	23-16
24-19	8-2	24-18	8-3	23-18	9-3	23-17	9-4	22-17
23-20	7-3	23-19	7-4	22-19	8-4	22-18	8-5	21-18
22-21	6-4	22-20	6-5	21-20	7-5	21-19	7-6	20-19

Table B8. Sample inter-SPO communications assignment table.

mean SPO, and that two are mini-SPOs, having half the geometric mean traffic. This consideration for unequal loading greatly impacts the timing efficiency of the transmission cycles. For example:

Given: SPO-1 and SPO-2 are the two super-SPOs.

SPO-3 thru SPO-21 are the "standard" SPOs.

SPO-24 and SPO-25 are the mini-SPOs.

Assume: The time required for a "standard" one-way message exchange volume (e.g., SPO-3 to SPO-4) is 5 minutes; for an exchange in both directions, 10 minutes.

Then the times (in minutes) required for exchanges between the combinations of SPO sizes are as follows:

SPO-1 and SPO-2 — 40

SPO-1 and SPO-3 — 20

SPO-3 and SPO-4 — 10

SPO-3 and SPO-25 — 5

SPO-24 and SPO-25 — 2-1/2

A diagram showing the message traffic flow volumes is presented in figure B23. The dynamic range of the two-way (and one-way) transmission time is the square of the ratio of the smallest to largest SPO traffic load, in our case 16:1.

The consequences of this disparity of message traffic volume is the long wait or idle time during each connection pairing. For this example, if the cycle time is chosen at 40 min, then SPO-1 and SPO-2 when interconnected by pairs will just finish the full batch of exchanges. The SPOs assigned to SPO-24 or -25 will have had 87.5% idle time, and when SPO-24 is connected to SPO-25, the idle time is 93.75%. Additionally, all "standard" SPOs that were interconnected will have 75% idle time. This is not really a very efficient procedure where a wide variation in mail traffic exists between stations.

A second disadvantage to this approach is that all outgoing mail must be presorted into the 24 destination SPO categories before transmission.

The current costs of landline/microwave communications can be calculated on the basis of a recent Navy procurement. A dedicated microwave link 200 miles long was leased for 10 years, 24 hours/day. The bandwidth is about 5 MHz and a few (three or four) repeaters are used in the link. The 10-year cost for this service is \$600M. Hourly costs can be calculated as follows:

$$\frac{\$600 \times 10^6}{10 \text{ years}} \times \frac{1 \text{ year}}{365 \text{ days}} \times \frac{1 \text{ day}}{24 \text{ h}} = \$6844.63/\text{hour}$$

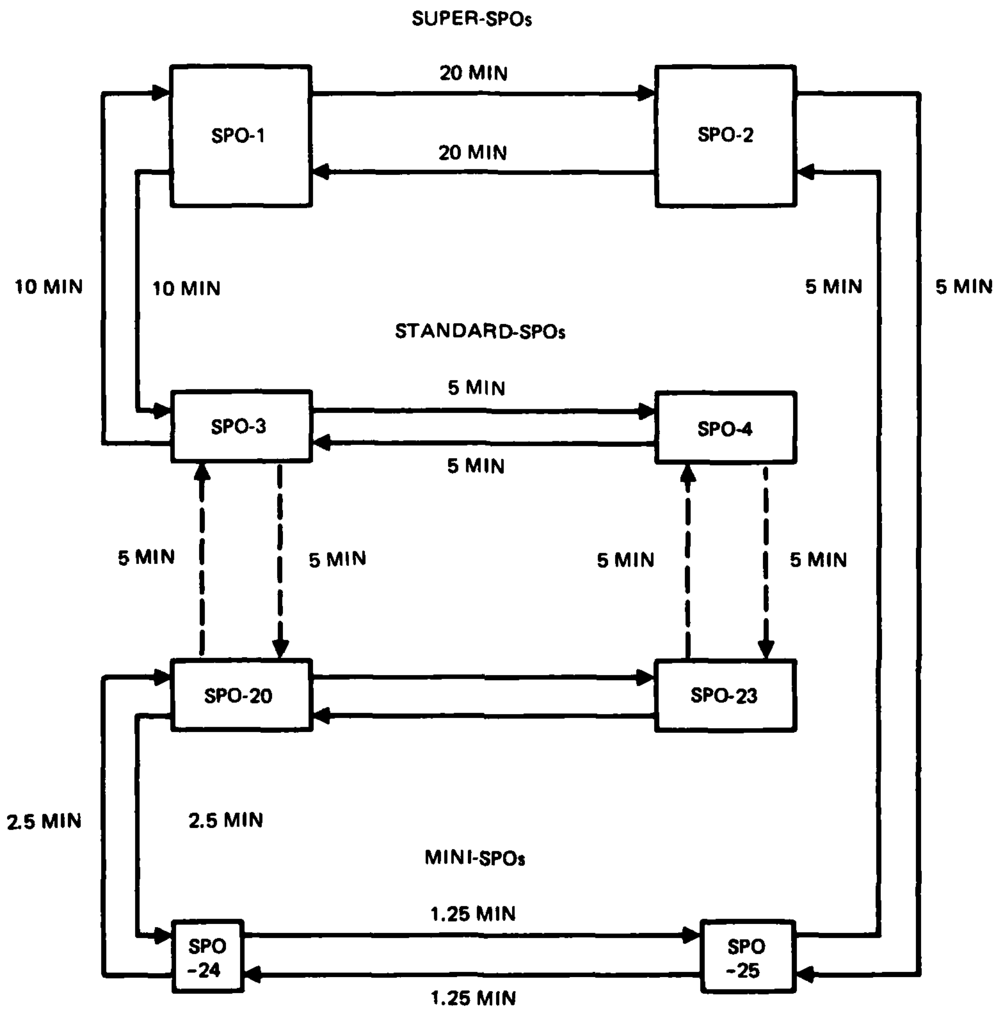

Figure B23. Message traffic flow times.

Figures B22b, and B22c depict the most probable alternatives for landline/microwave communication among SPOs. Figure B22b possibly could be instrumented to operate in the time division multiple access (TDMA) mode. It is possible to calculate the required bandwidth for a network operated on a full-time 24 hour basis.

Equation 1, states that $T = 6552 \times \frac{D}{B}$,

where T = total transmission time in seconds

D = daily messages transmitted

B = communication bandwidth in b/s

Rearranging eq 1, $B = 6552 \text{ X } \frac{D}{B}$,

and substituting for the first year estimate of 10^9 messages,

$$B = 6552 \times \frac{10^9 \text{ messages}}{\text{year}} \times \frac{1 \text{ year}}{300 \text{ days}} \times \frac{1 \text{ day}}{24 \text{ h}} \times \frac{\text{h}}{3600 \text{ s}}$$

$$= 252.78 \text{ Kb/s} \quad .$$

The transmission of 13.464 Mbytes/day of new full-page logos increases this bandwidth requirement by about one-half percent or 1 part in 200.

The above estimate can be modified to determine the bandwidths required for shorter transmission periods each day. For example, to calculate the bandwidth required if the daily transmission period is reduced to 3 hours, the time is reduced to 3/24, or 1/8. Multiplying the bandwidth required for 24-hour transmission by eight indicates the bandwidth needed for a 3-hour burst transmission exchange. This value for the first year 10^9 message/year estimate is 2.022 Mbits/s. Using an AT&T T-1 line at 1.544 Mbit/s in the TDMA mode, the daily exchange time would be

$$T = 6552 \times \frac{10^9 \text{ messages}}{\text{year}} \times \frac{1 \text{ year}}{300 \text{ days}} \times \frac{\text{s}}{1.544 \times 10^6}$$

$$= 14\ 154 \text{ s}$$

$$= 3.929 \text{ hours.}$$

Such a network necessarily would be expanded by a factor of ten to accommodate the fifth year message traffic.

6.3 SATELLITE COMMUNICATIONS

Figure B22d shows an inter-SPO network that uses a satellite for the networking connections. This configuration works very well in the TDMA mode. Each SPO is allowed to transmit in turn for a predetermined period. The satellite receives the data and retransmits the data toward earth, where all other SPOs are set in the listening mode to accept data for their specific series of ZIP codes.

This same network, exercised a few extra minutes per day in two additional reporting modes, could complete the daily interchange of USPS administration data and the transmission of new or modified logos.

For the transmission of new or modified logos, assume:

5000 E-COM customers during the fifth year

3000 use logos

Each customer changes his logo twice a year

Logos are full page

240 x 240 pels/inch resolution (5.3856×10^6 bits/page)

The daily logo upgrade traffic per day can be calculated as follows:

$$3000 \text{ customers} \times \frac{2 \text{ changes/year}}{\text{customer}} \times \frac{5.3856 \times 10^6 \text{ bits}}{\text{page}} \times \frac{1 \text{ year}}{300 \text{ days}}$$

$$= \frac{107.712 \times 10^6 \text{ bits}}{\text{day}}$$

= 107.712 Mb/day

= 13.46 Mbytes/day

This equates to a transmission time of 5.34 minutes at a rate of 336 Kb/s using six 56-Kb/s lines.

6.4 INTERCHANGE OF MAGNETIC TAPES

A standard reel of high-quality computer tape such as is now in use at E-COM SPOs has the following characteristics:

Length: 2400 feet

Width: 1/2 inch

Word width: 8-bit bytes plus parity

Packing density: 6250.bytes/inch

Moderately priced tape decks are available that will read and write at 6250 bytes/inch at 125 inches/second. From these parameters, the capacity and read/write rates for common tape storage can be calculated.

$$\text{Maximum tape volume} = \frac{2400 \text{ feet}}{\text{tape}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{6250 \text{ bytes}}{\text{inch}}$$

$$= \frac{180 \text{ Mbytes}}{\text{tape}}$$

$$= \frac{1.44 \text{ Gbits}}{\text{tape}}$$

$$\text{Maximum read/write rate} = \frac{6250 \text{ bytes}}{\text{inch}} \times \frac{125 \text{ inches}}{\text{s}}$$

$$= \frac{781.25 \text{ Kbytes}}{\text{s}}$$

$$= \frac{6.25 \text{ Mbits}}{\text{s}}$$

The daily message traffic for each of the three sizes of SPOs can be calculated for the estimated first year volume by using equation 1.

$$\text{Super-SPO volume} = \frac{2.56 \times 10^5}{\text{day}} \times \frac{1400 \text{ char}}{\text{message}} \times 0.45 \times 1.3 \times \frac{8 \text{ bits}}{\text{char}}$$

$$= 1.68 \times 10^9 \text{ bits/day}$$

On peak days (e.g., end of month, Christmas, Mondays, etc), the volume is estimated to be ten times the average, yielding a volume of 1.68×10^{10} bits/day.

From this, the standard-SPO peak message traffic would be half that of a super-SPO, or 8.39×10^9 bits/day.

The minimum number of tapes required if all traffic was destined for a single SPO is:

$$\text{No of tapes} = \frac{\text{daily volume}}{\text{tape capacity}}$$

$$= \frac{1.68 \times 10^{10} \text{ bits}}{1.44 \times 10^{9} \text{ bits/tape}}$$

$$= 11.67 \text{ tapes}$$

Rounding up = 12 tapes

It is unlikely, however, that all the traffic would be destined to a single SPO. Also the standard- and mini-SPO traffic will be less in volume. So it can be assumed that usually all traffic between each pair of SPOs can be contained on one tape. Thus, the maximum number of tapes to be generated would be 24, or one for each destination SPO. Assuming that each SPO has some messages for all other SPOs, then the number of tapes in daily transit among SPOs is:

$$25 \text{ initiating SPOs} \times \frac{24 \text{ destination tapes}}{\text{initiating SPO}} = 600 \text{ destination tapes.}$$

To schedule the interchange of tapes efficiently by some reliable high-speed transportation system, all message traffic must be sorted into the 25 SPO destinations (including local) immediately before the tapes are prepared. The tapes, in turn, should be prepared immediately before the available carrier services depart to the various destinations.

Time to prepare a full-length tape can be calculated:

$$\text{Run time} = \frac{2400 \text{ feet}}{\text{tape}} \times \frac{12 \text{ inches}}{1 \text{ foot}} \times \frac{1 \text{ s}}{125 \text{ inches}}$$

$$= 230.4 \text{ s/tape}$$

$$= 3.84 \text{ min/tape}$$

$$\text{Rewind time} = \frac{3.84 \text{ min}}{\text{tape}}$$

$$\text{Mounting, threading, unload time} = \frac{1 \text{ minute (or less)}}{\text{tape}}$$

$$\text{Total handling time} = \frac{3.84\ \text{min}}{\text{tape}} + \frac{3.84\ \text{min}}{\text{tape}} + \frac{1.0\ \text{min}}{\text{tape}}$$

$$= \frac{8.68\ \text{min}}{\text{tape}}$$

For preparation of the 24 tapes leaving each SPO the total time required is as follows:

$$\text{Preparation time} = 24\ \text{tapes} \times \frac{8.68\ \text{min}}{\text{tape}}$$

$$= 208\ \text{min}$$

$$= 3.47\ \text{hours}$$

This represents a worst-case time estimate based on running the tapes sequentially from start to finish on one tape transport. During the first and second years of E-COM, most tapes would probably be filled to less than half capacity.

Tapes received at each SPO will probably be unloaded onto disks along with information received from the 23 other SPOs plus the local traffic remaining to be merged and sorted. A practice of retaining the information on the received tapes until assurance of delivery is confirmed should be enforced. Once this assurance is received, the tapes should be degaussed to guarantee privacy. This practice will also preclude the need to erase previous data by use of the tape deck, thus will prevent duplicate transmissions.

A very well planned tape library system must be established and maintained to control the cylic reading, storage, writing, and shipping process.

ANNEX 1

TO

APPENDIX B

DOMESTIC COMMUNICATION CARRIER DATA

From

RCA Americom

Satellite Business Systems

AT&T Long Lines

ANNEX 1 (APPENDIX B) CONTENTS

RCA AMERICOM
Satellite Communications
Princeton, NJ
(609) 734-4352
L. Scott
2 December 1982

Cost Estimates

A 10-meter dish on SPO site for dedicated wideband communication costs approximately $\frac{\$11\text{k/month}}{\text{SPO}} \times 25$ SPOs plus the following:

Full 34 Mb/s simplex channel capacity—$129 166/month.

Channel capacity is available in modular increments as follows:

56 Kb/s	(0.16% of BW) =	$212/month
T-1—1.544 Mb/s	(4.54% of BW) =	$5865/month
T-1C—3.15 Mb/s	(9.26% of BW) =	$11 967/month

These three costs must be doubled when using TDMA, because system control requires full duplex.

56 Kb/s:	$212/month × 2 = $424/month
T-1—1.544 Mb/s:	$5865/month × 2 = $11 730/month
T-1C—3.15 Mb/s:	$11 967/month × 2 = $23 934/month

NOSC estimate of first-year average requirement = 252.78 Kb/s (see para 6.2 in appendix B) or approximately 5 or 6 56-Kb/s channels in TDMA satellite mode = 336 Kb/s

$$\frac{336\ \text{Kb duplex}}{\text{s}} \times \frac{\$129\ 166}{34\ \text{Mb/s simplex month}} \times \frac{2\ \text{simplex}}{\text{duplex}} = \$2553/\text{month.}$$

Total first-year annual recurring cost:

$$\text{Site lease cost} = \frac{\$11\ 000}{\text{site month}} \times 25\ \text{sites} \times 12\ \text{months}$$

$$= \$3.3\text{M}$$

$$\text{Total cost} = \$3.3M + \frac{\$2553}{336 \text{ Kb/s/month}} \times \frac{12 \text{ months}}{1 \text{ year}}$$

$$= \frac{\$3.31M}{336 \text{ Kb/s per year}}$$

Total estimated fifth year annual recurring cost:

Site lease cost = \$3.3M

$$\text{Total} = \$3.3M + \frac{\$2553 \times 10}{3.36 \text{ Mb/s per month}} \times \frac{12 \text{ months}}{1 \text{ year}}$$

$$= \frac{\$3.606M}{3.36 \text{ Mb/s per year}}$$

It should be emphasized that this is a very simplistic baseline estimate. Not included are encryption/decryption formatting, annual site maintenance services, special modem format leases, etc.

NOTES:

1. Major Americom Cities: NYC, SF, LA, CH.

2. Costs are for "protected service." Your site crashed, you preempt someone else's unprotected service.

3. Encryption/decryption is available up to 1.544 Mb/s (T-1) speeds. Satisfy NSA, but not for secret data. (CY-104 MIL or KG-34 MIL).

4. Bit error rate (BER) for 56 Kb/s line is 10^{-6}.

5. Many ways to format data, e.g., six 56-Kb/s pipes with down-links, retaining six separate message streams on one (56K × 6) 336 Kb/s-channel, etc.

6. RCA does not sell time slots for parts of days yet. All services are for full-time 24 hour per day netting.

7. L. Scott would be pleased to present his company capability to the USPS at Rockville.

SATELLITE BUSINESS SYSTEMS
8283 Greensboro Drive
McLean, VA 22102
(703) 442-6036
CR Driscoll
24 November 1982

During a visit by P Grossnickle and F Martin, CR Driscoll and L Bishop explained the operation of their satellite systems. They also provided us with several brochures explaining the tariff structure for various options. Some data are included here. CR Driscoll would be very pleased to present operational data and pricing options to the USPS at Rockville.

NOTES:

1. Maximum bandwidth per dish = 48 Mb/s.

2. Port adapters are available for 56 Kb/s, 1.544 Mb/s, and 3.088 Mb/s, up to 48 Mb/s total.

3. Average rule of thumb installation cost per site = $150k--$250k.

4. Average installation time = 12 to 18 months from agreement.

5. Encryption/decryption is available.

6. Customer can procure parts of a day, and nonbusiness hours are significantly less expensive.

7. Capacity can be divided into many small channels or can be one big hose.

AT&T LONG LINES
Washington, DC
(202) 457-3544
C Wilson
29 November 1982

After a series of calls from the west coast in an attempt to locate technical bandwidth, bit error rate, location of trunk routes, and tariff data, I received a call from C Wilson in Washington, DC. He has called twice since for more information but has not yet provided answers to any of my questions. He states that he will provide information for us.

20 September 1983

No further word has been received from C Wilson or his office. The Washington, DC, telephone directory indicates that the proper place to obtain rates on long lines is the long lines office (the first entry under AT&T). We have no such office in San Diego. When additional specific long lines tariff or technical data are needed, we shall contact that office. C Wilson is apparently in AT&T Government Marketing.

ANNEX 2

TO

APPENDIX B

BILEVEL INTERPOLATION

The mapping from the printed logo space into the sample logo space is linear, and the interpolation itself is bilevel. Let the sample logo matrix be I by J and the printed matrix M by N. The (m,n) pel in the print matrix maps to (x,y) in sample matrix space, where

$$x = m\ (I/M)$$
$$y = n\ (J/N).$$

If nearest neighbor interpolation is used, the printed pel, P(m,n), at location (m,n) assumes the value of the sample pel, S(i,j), at location (i,j). That is:

$$P(m,n) = S(i,j),$$

where

$$i = \text{round}\ (x)$$
$$j = \text{round}\ (y).$$

Another interpolation scheme is three nearest neighbor interpolation. With this, the printed pel P(m,n) is black only if all three of its nearest neighbors in the sample matrix are also black. With nearest neighbor interpolation, the center of a printed black pel may be outside the sample logo black area border by a maximum of 1/2 the sample logo spacing. With three nearest neighbor interpolation, the center of a printed black pel will always be within the black area of the sampled logo matrix.

Consider now the distortion that results from resampling the sample logo matrix to obtain the printed matrix. Assume a logo containing a straight vertical (or horizontal) black-white border. It is digitized with detectors having symmetrical spatial transfer functions, and the bilevel threshold is set midway between the black and white response. Further, assume that nearest neighbor interpolation in the sample matrix is used to obtain the printed matrix.

Let

$$K = \text{effective sample pel spacing}$$

$$= 1/[(\text{sample resolution}) \times (\text{logo size ratio})],$$

$$L = \text{printed pel spacing},$$

$$R = \frac{\text{width}}{2} \text{ of printed pel, assumed square.}$$

Simple analysis shows that the error in the location of the printed black-white border relative to the corresponding border in the sample logo is bounded as follows:

$$-(K/2 + L-R) \leq \text{location error} \leq (K/2 + L-R).$$

If R = L/2, i.e., if the printed pel width equals the printed pel spacing, then

$$\text{abs (location error)} \leq (K/2 + L/2).$$

Except for a factor, the results are similiar for diagonal borders.

Without bilevel interpolation, the location error would be only L/2. Thus interpolation adds a factor of K/2, where K is the effective spacing of the sample pel matrix. Although further study is necessary, this result points to the desirability of digitizing the sample logo with high effective resolution, where bilevel interpolation is to be used within the resulting matrix.

This apparent need for high effective resolution in the sample logo implies a larger storage requirement for the logo masters. If a logo printed at 240 pels/inch is digitized at an effective resolution of 720 pels/inch, for example, memory usage increases ninefold relative to digitizing at 240 pel/inch resolution. However, it is necessary to store only one master per logo. Since the logo masters will be accessed infrequently, they can be archived in a tape library.

APPENDIX C

NOSC LOGO PROJECT PLAN FOR

GRAPHICS CONVERSION SUBSYSTEM

APPENDIX C CONTENTS

APPENDIX C ILLUSTRATIONS

INTRODUCTION

The USPS currently offers a service called Electronic Computer Originated Mail (E-COM), wherein customers transmit messages to Serving Post Offices (SPOs) via telecommunications channels. At SPOs, these messages are sorted, printed, enveloped, and merged with the first-class mail stream.

The USPS plans to upgrade the current E-COM service by adding customer-defined graphics to E-COM messages. These graphics initially will consist of company logos but may later include letterheads, signatures, and other message features.

NOSC has provided technical support to the USPS, primarily in imaging technology, for about 9 years. Currently, NOSC is studying alternatives for the planned E-COM logo service. This effort has focused on logo acquisition, compression, storage, transmission, and printing. Among these topics, logo acquisition and printing present the most challenging and important technical problems. Both will influence the quality of the printed message and the efficiency of the logo service.

During the course of these investigations, NOSC has evolved a set of promising approaches to logo acquisition and logo printing. It is felt that logos can be digitized by coupling a set of equipment made by the Datacopy Corporation with a microcomputer host. Renaissance Marketing has integrated a printer from Delphax with an LSI-11/23 based controller. This promises high-speed, high-resolution, low-cost printing of E-COM messages with graphics, but there are numerous technical questions regarding the *implementation of these equipments.*

NOSC now is recommending hardware for assembling a prototype graphics conversion subsystem. This will allow validation of concepts for logo aquisition, editing, and formatting for use in E-COM.

A key feature of the NOSC proposal is the plan to use the same host processor for both the Datacopy logo digitizing equipment and the Delphax printer. The controller for the Delphax printer is an LSI-11/23 CPU with a VT-100 terminal, a dual floppy disk drive, and a tape drive. With some enhancements, this system will serve as a host for the Datacopy equipment.

This appendix

1. Describes the hardware and software that NOSC proposes to be purchased and developed in-house.

2. Details the configuration of the proposed graphics conversion subsystem.

3. Lists the tasks required to integrate and develop this system at NOSC.

4. Describes the evaluation of both the procured equipment and the techniques for digitizing, editing, and printing logos.

5. Lists the deliverables to the USPS by NOSC as a result of this effort.

PROTOTYPE GRAPHICS CONVERSION SUBSYSTEM

The graphics conversion subsystem proposed by NOSC (fig C1) will perform two primary functions:

Digitize, store, and display a logo.

Edit, format, and store the digitized logo on disk or tape.

The first function will be provided by equipment purchased from Datacopy Corporation. The second function will be controlled by the LSI-11/23 based host processor. The logo will be scanned by a digitizing camera mounted on a camera stand. The output from this camera will be thresholded and stored in a 1728 by 2200 pel frame store memory from which a bilevel monitor is refreshed with the entire image. The processor will then read from the frame store memory a subimage containing the logo. Several approaches to logo editing will be evaluated. The logo can be edited either on the Datacopy display from the VT-100 terminal or on a special graphics terminal. Finally the edited logo will be stored on disk or tape.

RECOMMENDED PROCUREMENTS

GRAPHICS CONVERSION SUBSYSTEM DIGITIZING EQUIPMENT

The USPS has initiated a procurement for the following equipment from Datacopy Corporation:

(1) Digitizing camera (Model C322)
(2) Camera control unit (Model 340)
(3) Display system (Model 521)
(4) Computer interface for LSI-11 Q-bus (Option 81)
(5) Lens mount for Nikon lens (Model 300-N)

Additional required items are a copy stand and an illumination source with power supply. These items will be purchased by NOSC. NOSC has on hand an Auto Micro Nikkor lens for the digitizing camera.

GRAPHICS CONVERSION SUBSYSTEM HOST COMPUTER SYSTEM

It is proposed that for the prototype development the same LSI-11/23 used for the Delphax printer controller be used. It contains an LSI-11/23 CPU with the floating point option, running under the RT-11 operating system. Its peripherals include a magnetic tape drive, a VT-100 terminal, and dual floppy disk drives. NOSC intends this microcomputer to have a dual role: it will serve both as a printer controller and as a host for the Datacopy digitizing equipment. To perform this second function, the LSI-11/23 system will require some enhancements, which are described below.

The LSI-11/23 system, as configured by Renaissance Marketing, has only one serial interface port (DLV11-F), which is used for the VT-100 terminal. At least three serial ports will be needed for the graphics conversion subsystem prototype: one to the VT-100, one to the Datacopy camera control unit for scan control, and one to a line printer for software development.

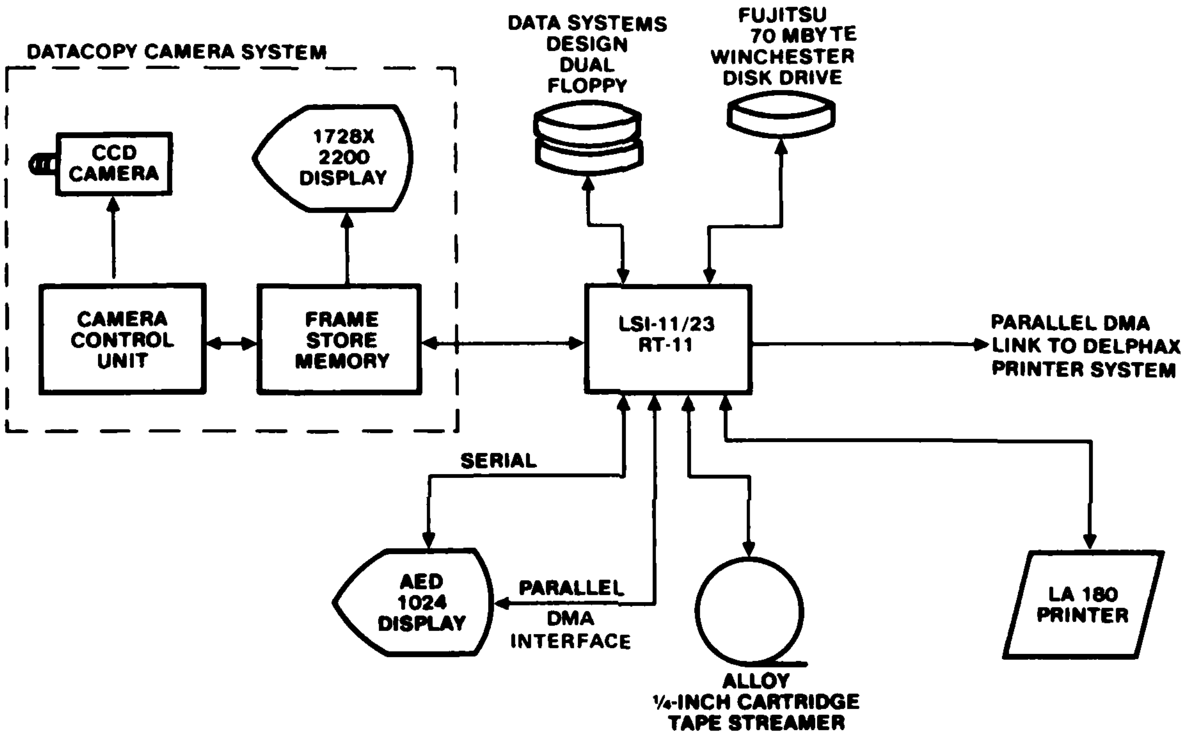

Figure C1. Prototype graphics conversion subsystem.

Thus NOSC will procure a DLV11-J quad serial interface card to the replace the DLV11-F. For software development, NOSC will use the Tektronix 4641 line printer currently in the ICAS lab.

For logo editing, NOSC proposes to evaluate several approaches. For the first approach, software would be written to send zoomed, or enlarged, logos to the Datacopy display and to allow editing to be controlled via the VT-100 terminal. The image data transfer time and response of the editing commands may be rather slow. As an alternate approach, a graphics terminal would be interfaced to the LSI-11/23 Q-bus for logo editing. An AED 512 graphics display terminal will soon be acquired by another project at NOSC, and it is anticipated that this terminal can be borrowed for evaluation as a logo editor on the graphics conversion subsystem. It would serve a dual role in that it can replace the VT-100 terminal, since it has built-in terminal functions as well as the graphics capabilities.

The AED 512 contains a bit-mapped memory that can be configured as 1024 by 1024. It allows viewing a 16:1 zoomed image in a 512 by 483 window while roaming about the 1024 by 1024 memory under joystick control. It costs about $9k. To test the terminal with the prototype graphics conversion subsystem, it would be necessary only to buy an LSI-11 Q-bus interface for the AED 512, which costs about $1k.

The AED 512 is not necessarily the final recommended choice for the graphics conversion subsystem. Annex 1 details the characteristics of the AED 512 as well as several other contenders that will be evaluated when information is received.

DEVELOPMENT TASKS

SYSTEM INTEGRATION

Several types of equipment must be integrated for the prototype graphics conversion subsystem development effort. The major tasks are listed as follows:

Initiate procurement of the camera copy stand, including the illumination source and power supply.

Initiate procurement of additional interface cards for the LSI-11/23 host.

Integrate Datacopy frame store memory and camera control unit with LSI-11/23.

Select and procure Winchester disk for logo storage, and interface it to the LSI-11/23.

Integrate line printer with LSI 11/23.

Test Datacopy equipment by scanning, thresholding, storing, and displaying test logos.

Integrate AED 512 graphics terminal with LSI-11/23, and test.

SOFTWARE DEVELOPMENT

The main tasks to be performed by the graphics conversion subsystem are summarized here. The functional specification of the software will begin immediately so that software development may be started as soon as the equipment arrives.

Logo capture and display

This task will generate the camera control signals necessary to issue repeated scan commands, so that the optimum threshold can be found.

Write zoomed image to Datacopy display

This will allow the operator to select a portion of the scanned image and cause it to be enlarged and written into a portion of the display memory for editing.

Transfer data to AED 512 display

As an alternative, logo editing operations will be tested by means of the AED 512 graphic display terminal. This software will be used to transfer up to a 1024 by 1024 pel segment of an image to the AED 512 display for editing.

Edit image in Datacopy display memory

In the image display area a cursor will be generated that may be moved by using cursor control keys. When a pel is found that needs altering, a keystroke will cause the indicated pel to be inverted. These operations are thought to be difficult to perform with reasonable time response from the display system.

Edit logo data in AED 512 display memory

When the display memory is configured as 1024 by 1024, the joystick on the terminal may be used to roam over the image to look at a 512 by 483 segment of the image. This image may also be zoomed up to 16:1 by means of hardware functions. The displayed image may be frozen and the joystick used to position a cursor on a single pel for editing. It is believed that this operation will be very easy to perform and will be very responsive to the operator.

Logo data formatting and storage

When the editing process is complete, the data must be formatted and stored on disk or on magnetic tape. The data formats are still under investigation since there are now two possible configurations for the Delphax printer controller. If a printer architecture is chosen that uses compressed data, then the formatting software will need to perform the appropriate data compression algorithm.

Verification printing of logos

This software will allow the edited logos to be printed for customer verification and acceptance.

EVALUATION TASKS

After the prototype graphics conversion subsystem has been assembled, it will be evaluated relative to the E-COM mission. Of particular interest is the quality of digitized logos and the ease with which logos can be digitized and edited. In addition, NOSC will study the feasibility of specific enhancements to this subsystem, such as modification of the camera for nonsquare scanning and logo scaling in software.

1. DIGITIZING SYSTEM

Camera

- Linearity of response
- Resolution (modulation transfer function)
- Sensitivity
- Output noise
- Interface parameters

Illumination source

- Adequacy for sensor response
- Uniformity across target image plane

Threshold Circuit

- Response time
- Uniformity

Monitor

- Resolution
- Flicker
- Uniformity of response

2. LSI-11/23 SYSTEM

Time to perform various data tranfers
System features relative to scan control and logo editing

3. HUMAN FACTORS

Logo Scanning. Simplicity of adjustments, fatigue, accuracy, speed and of operation, and time and effort required to adjust the following:

Camera height
Camera focus
Camera aperture
Illumination intensity
Logo position and orientation
Threshold setting

Logo editing

Cursor control
Ease of logo cosmetic repair

4. ENHANCEMENTS TO THE PROTOTYPE GRAPHICS CONVERSION SUBSYSTEM

These tasks will study the feasibility of the following system upgrades:

Modification of the camera for

Nonsquare scanning resolution
Slower scan speed to allow DMA transfer to host

Logo scaling in software

"Tiling" logo subimages to generate full-page logos

SCHEDULE

Figure C2 is a milestone chart showing a tentative schedule for the graphics conversion subsystem development. As details are derived for the various tasks, additional entries will be made on the chart.

	7	8	9	10	11	12	1	2	3	4
RECEIVE:										
DATACOPY	X									
COPY STAND			X							
DELPHAX			X		X*					
SOFTWARE:										
SPECIFICATION	S	----	E							
CODING			S	----	E					
HARDWARE TESTS:										
DATACOPY	S	E								
DELPHAX			S	E						
SYSTEM				S	----	----	E			
INTERIM REPORT									X	

MONTH 1983/1984

*POSSIBLE ADDITIONAL PURCHASE OF NEW ARCHITECTURE IMAGE GENERATOR FOR DELPHAX PRINTER.

Figure C2. Milestone chart for graphics conversion subsystem.

ANNEX 1

TO

APPENDIX C

GRAPHICS TERMINAL

JUSTIFICATION AND ALTERNATIVES

JUSTIFICATION FOR THE AED 512

The current plan for the graphics conversion subsystem includes the use of an AED 512 for the purpose of editing logos acquired with the Datacopy camera. This approach has several advantages, as listed below.

1. NOSC will have one in place on another project, and it may be borrowed for evaluation purposes. As a result, most or all of the necessary software device drivers already will be developed and available for immediate incorporation into the graphics conversion subsystem.

2. The AED 512 has a high-speed DMA port that allows data transfer at a rate of about 512 kbytes/second, allowing the display to be loaded in about 0.5 second. (This assumes that the host can accommodate that rate.)

3. It allows a virtual display area of 1024 × 1024 pixels, with a display window (physical display area) of 512 × 483 and local pan and zoom functions.

4. It is PLOT-10 compatible, which means that the PLOT-10 software could be purchased from Tektronix, yielding substantial off-the-shelf enhancement to the graphic manipulation capabilities (although this would probably not be necessary).

5. The price is only about $7500 (after 20% government discount).

The AED 512 has one significant disadvantage: the display size is only 13 inches (diagonal). In addition, there is a contrast filter over the face of the tube, which greatly reduces the visibility of the image.

ALTERNATIVES

Many companies offer graphics or image processing stations that satisfy the functional requirements of the graphics conversion subsystem graphics terminal. Unfortunately, most of them provide drastic overkill for the functionality required in this subsystem, and their prices are commensurate with their functional capabilities.

There are a few units, however, to which consideration should be given for use in this subsystem. The most promising of these is the Genisco G2000, which has a 19-inch display with a 1024 × 792 pel resolution, considered to be substantially better than the AED display. The G2000 does not have a parallel DMA interface but does have an RS-422 high-speed serial interface, allowing approximately 100 kbaud transfers. Thus it would take about 10 seconds to transfer a full image from the host to the terminal.

Otherwise, the G2000 has all the functionality of the AED 512 plus the added benefit of being able to emulate the DEC VT100. Therefore, the functions of the VT100 (cost about $4000), originally intended as the operations console, and the logo editing terminal could be combined in one package. Use of the G2000, at $12 500, would cost only marginally more than the combination of the AED 512 and the VT100 and would require less desk space. It would, however, require some software development, probably only for the actual data transfers.

Other products are currently being investigated as possible graphic editing terminals, all of which have 19-inch displays and at least 512 × 512 pel resolution. In addition, it is felt that as a minimum capability, the candidate selected must have local pan and zoom with joystick or thumbwheel control, some local programmability (e.g., function keys), single-pel edit capability, and full display transfer in less than 15 seconds.

Manufacturers being considered (pending receipt of additional data) are Megatek (the Whizzard series), Chromatics (CGC series), and Data Type (AutoGraph series).

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